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(UNCLASSIFIED) LANDING VERTICAL VELOCITY AND ACCELERATION MEASUREMENTS OF BERLIN AIRLIFT C-54 AIRCRAFT

J. J. SAUNDERS
G. F. PIPER

THE GLENN L. MARTIN COMPANY

JULY 1953

Statement A
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WRIGHT AIR DEVELOPMENT CENTER

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(UNCLASSIFIED) LANDING VERTICAL VELOCITY AND ACCELERATION MEASUREMENTS OF BERLIN AIRLIFT C-54 AIRCRAFT

This report supersedes AFTR 5787,
same subject, dated November 1950.

J. J. Saunders
G. F. Piper

The Glenn L. Martin Company

July 1953

Aircraft Laboratory
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Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

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FOREWORD

This report is the end product of an Air Force and Bureau of Aeronautics cooperative effort to obtain landing velocity measurements for the transport type aircraft operated during the Berlin Airlift. The photographic film records were obtained by a group from the Naval Air Experimental Station, Philadelphia consisting of the following: Messrs. E. R. Armstrong and M. J. Eagan photographers, and Messrs. R. F. Kelly, C. W. Pearson and M. E. Soennichsen, engineers.

The analysis of the photographic records of the landings was sponsored by the Aircraft Laboratory of the Wright Air Development Center under Contract Number AF33(038)-9351 and AF33(616)-397 with the Glenn L. Martin Company who performed the film analysis and prepared this report. The film analysis was monitored by the Dynamic Test Section of the Aeronautical Structures Laboratory of the Naval Air Experimental Station. The contract was initiated under a research and development program, Aircraft Dynamic Loads, identified by RDO number 451-373 (unclassified). The project was coordinated by Messrs. J. P. Wamser project engineer for the Structures Branch, Bureau of Aeronautics and W. J. Lunney project engineer for the Aircraft Laboratory.

This report is classified RESTRICTED since it reveals data relating to the development of dynamic landing load criteria. Consequently the release of this report to foreign nationals is not authorized except in accordance with approve policies and procedures.

NOTE: The results of these landing measurements were originally presented in AFTR 5787 dated November 1950. Subsequent to publication inaccuracies were found which led to the need for revision. This report supersedes AFTR 5787. Copies of AFTR 5787 existing should be returned to The Commander, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, Attn: WCLSY.

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ABSTRACT

Photographic records of landings of the Berlin Airlift with C-54 aircraft have been analyzed. The results have consisted of sinking speeds, accelerations, horizontal speeds, and wing load factors at touchdown during landing. The analysis has been conducted for the purpose of obtaining accessory data that can be used in arriving at a design criterion for the selection of limit sinking speeds of land based aircraft. The probability of equalling or exceeding a given sinking speed or horizontal speed has been calculated and presented in curve form. The limitations of the results concerning the extension of the data to cases not included in the analysis have been indicated. The nature and scope of further sampling have been discussed. Suggestions have been made concerning the usage of this and future data.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

for DANIEL D. McKEE
Colonel, USAF
Chief, Aircraft Laboratory
Directorate of Laboratories

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SECTION I

INTRODUCTION

Until recently it has been customary to select maximum landing vertical reactions on entirely theoretical considerations or drop test data. The rationality of the procedure has not been substantiated by actual operational flight test data. The object and scope of the subject analysis is not to demonstrate whether the criteria used in the past were right or wrong, but simply to present accessory data and formulate the basic thinking which will enable utilizing this and similar empirical data in the formation of realistic landing design criteria.

A growing appreciation of the problem of fatigue life expectancy of landing gears and their support structure has brought forward the necessity for data concerning the relative frequency of service horizontal landing speeds. Data of this nature can be used in the prediction of the frequency of service landing drag loads. Although secondary to the initial purpose of the analysis, the compilation and interpretation of these Berlin Airlift horizontal landing speeds have been considered pertinent.

A photographic method of filming and analyzing landings has been used for measuring the landing velocities. The method has been designed for this purpose by the Aeronautical Structures Laboratory of the Naval Air Experimental Station, Philadelphia, Penna. Its most salient advantage consists of not requiring any instrumentation of the airplane being observed. As a result, it enables the observation of a large number of random landings at minimum cost and effort.

The Berlin Airlift afforded an excellent opportunity for obtaining landing data for many landings were taking place in a short interval of time, thus minimizing the length and cost of the filming operation to obtain many random observations. Also, the landing weight of the C-54 aircraft at the two airports selected for the observations, Tempelhof and Rhein-Main, was practically constant (67,900 lbs and 46,800 lbs respectively). It was considered that the difference in landing weight would show its effect on the magnitude of sinking speed.

It should be pointed out that the landing approach pattern at both the airfields concerned was monitored by a GCA System which was markedly successful in preserving the continuity of the airlift landing operations in foul weather. Landing procedures were prescribed for each airfield and pilots were regularly checked in the procedure. Under good visibility and ceiling conditions, which existed at the time these film records were made, GCA landing instructions were furnished including the final approach glide path corrections. It is estimated that under these conditions approximately 90% of the pilots utilized the glide path corrections until field boundary obstructions were cleared. At Rhein Main airfield the standard GCA 2-$\frac{1}{2}$ degree, 500ft/min sinking speed glide path was utilized. However field boundary obstacles at Tempelhof airfield required use of a steeper glide path which resulted in a sinking speed of 750/ft/min on the approach glide.

The C-54 type aircraft formed the majority of the aircraft involved in the Berlin Airlift operation.

SECTION II

SUMMARY

The experimental procedures and reduction of data which form the basis of the photographic method have been fully described in this report. It should be noted, however, that certain refinements of the original method have been effected during the performance of the subject analysis. The most significant of these refinements has been the replacement of the third degree polynomial used for the calculation of sinking speed by a second degree polynomial that fits the space time data more accurately. As a result, the original Naval Air Experimental Station report which describes the method (Ref. 1) will not be readily available until the above and other minor revisions have been incorporated. This has prompted the inclusion of a comprehensive description of the modified method in the body of this report.

A total of 567 landings was filmed during the Berlin Airlift for this analysis. Of these, 374 took place at Tempelhof and 193 at Rhein-Main. However, because of lack of distinctiveness of the airplane image on the film and other reasons, a total of 292 landings was found unsuitable for analysis. Of the remaining 275 that have been analyzed, 187 took place at Tempelhof and 88 at Rhein-Main.

An attempt was made to determine the effect of cross-wind on the magnitude of sinking speed during landing. The results have indicated that there is no effect. However, it has been concluded that any possible effect of cross-wind may be concealed by the pilot's all-controlling effect on the magnitude of sinking speed in spite of the physical variables incidental to a normal landing.

The maximum and minimum sinking speeds have been -7.23 and -.05 feet per second at Tempelhof (heavy weight landing condition) and -6.43 and -.71 feet per second at Rhein-Main (light weight landing condition). From a statistical viewpoint, the difference between the frequency distributions of sinking speeds within each sample (landing condition) is not significant. It has been concluded that two samples are not enough data to establish the possible effect of landing weight on the magnitude of sinking speed. Moreover, it has been suggested that, for simplicity, the samples be considered as two sets of observations of homogeneous events, and the effect of physical variables such as landing weight be neglected.

The two samples of sinking speed have been found inadequate for generalizing the conclusions applying to cases not included in the analysis. It has been observed that before it is possible to arrive at a criterion for the selection of sinking speeds for design purposes, many samples must be obtained which should include the effects of all the various physical variables incidental to landings. Nevertheless, in the absence of data of more universal value, the results of the subject samples of sinking speed could be used as guides for the practical engineering problem of selecting design limit sinking speeds for landbased airplanes. For this purpose, a curve of probability of equaling or exceeding a sinking speed has been presented for each of the two samples.

A curve of probability of equaling or exceeding a horizontal landing speed has been obtained for each of the two landing weight conditions. To enable a comparison of the two samples, the speeds

have been expressed as ratios of the landing true airspeed to the stalling speed of the C-54 aircraft at sea level for maximum landing weight without flaps. The difficulty of generalizing the frequency distributions of horizontal landing speed is similar to that of the sinking speed.

The acceleration of the landing main wheels at an instant just prior to touchdown has been assumed to be equal to the acceleration at the C.G. of the airplane at the same instant. In this manner, the acceleration in g's has been considered to be equal to the increment wing load factor at touchdown, and a curve of wing load factor at touchdown versus sinking speed has been plotted for each of the two landing weight conditions. This data, although not precise, can be used as a guide for the selection of the magnitude of simulated wing lift during translational drop tests.

Some suggestions have been made concerning the isolation of the basic factors that enter into the formation of criteria for the use of sinking speeds for design purposes. It has been concluded that three populations of sinking speeds should be considered, depending on the medium on which the landings are performed, the mediums being carrier, land, and sea. Moreover, the selection of a design limit sinking speed for any particular airplane design within each medium should be the result of a logical compromise between facts (probability of occurrence of sinking speeds) and policy (expendability, operational purpose and efficiency, and cost of the airplane).

The result of the analysis of each individual landing, a sample of calculations of sinking speed, acceleration, and horizontal landing speed, are presented in Appendix 1.

SECTION III

DESCRIPTION OF

EXPERIMENTAL PROCEDURES

General

The photographic method consists of obtaining film records of landings with a high speed motion picture camera. A continuous time record is provided by placing a precision timer in the field of view of the camera. The timer is independent of film speed. The experimental data is obtained by taking certain measurements that locate the airplane on the projected film. Corrections of the measurements are made to take into account the scale reduction of the images on the film and the airplane image foreshortening. An equation is obtained

for the curve of best fit through the space-time observations taken from the films. The first and second derivatives of this equation result in the sinking speed and acceleration of the main landing wheels at touchdown. A mathematical method of analysis is also used to determine the horizontal landing speed at touchdown (Ref. 1).

In order to simplify and condense the mass of data on sinking speed and horizontal landing speed so that the characteristics of the elements of the data may be distinguished and their significance appreciated, the sinking speeds and horizontal speeds are presented in the form of curves of probability of equalling or exceeding either speeds. Areas of Pearson's Standardized Type III Function are used to obtain the probabilities (Ref. 2 and 3).

Equipment for Obtaining Film Records

1. Camera

A 35 mm Mitchell high speed motion picture camera is used to obtain the film records. Its operating speed can be varied and adjusted (between 50 and 100 frames per second) for filming throughout a reasonable range of lighting conditions, thus producing images which are in most cases sharp and well-defined. Other features of the camera that provide flexibility to meet a wide variation of runway or carrier operation are (1) a lens turret mounting four focal length lenses (50 mm, 40 mm, 35 mm and 25 mm); (2) a provision for inserting special film framing masks and (3) a focusing, telescoping viewfinder equipped with a variable magnification system of 5 and 10 power. When the camera is aligned or focused, the entire camera box is moved sideways behind the lens turret. This moves the viewfinder directly behind the lens being used and eliminates parallax.

For runway operation, the camera is mounted on a micrometer leveling head which is bolted to the tilthead of a low camera tripod. When the camera is operated on a dirt or asphalt surface, the tripod legs are placed on a triangular metal base to prevent any change of camera position. A precision clinometer is used for leveling the camera. Prior to landing operations, the film speed is set to the desired value by a rheostat mounted externally on the 110 volt motor drive of the camera and thereafter remotely controlled by a "Variac" placed at a safe distance from the landing area. Figure 1 shows the equipment as it is set up to record runway landings.

2. Precision Timer

A one revolution per second precision timer is used which has a synchronous motor drive controlled by a frequency generator. The dial, which is 21 inches in diameter and marked off in 1/100 second intervals, was designed for easy and accurate reading. The timer operates on 110 volts, 60 cycle alternating current and receives a constant 60 cycle frequency input from a precision calibrated frequency generator. A holder for number plates to record and

identify the number of each landing is attached to the moisture-proof timer case (See Figure 3).

Equipment for Film Analysis

An Eastman Model C "Recordak" Library Film Reader and a film assessing graticule, the latter designed by the Naval Air Experimental Station for use with the "Recordak" are used for reading the film records. The "Recordak" produces an image magnification (between 12 and 14 times the size of the film image) of a convenient size for obtaining accurate measurements. The film assessing graticule, which replaces the original "Recordak" viewing screen, was developed by NAES to improve the reading accuracy and reduce the reading time of the film. Horizontal measurements are taken from the 1/50 inch transparent scale on the crosshead. Vertical measurements are taken from the 1/50 transparent scales attached to the back surface of the viewing screen. Horizontal and vertical reference lines are on the crosshead and the crosshead slide, respectively. Figure 2 shows the "Recordak" with the assessing graticule installed and Figure 3 shows the graticule with a film image projected on the viewing screen.

Technique of Obtaining Records

The photographic records of runway type landings are taken with the camera located 50 feet on the left side of the runway and 150 feet forward of the center of the probable wheel touchdown area. The camera is leveled with the precision clinometer and then aligned by sighting the vertical reference line in the focusing telescope on a stadia rod placed on the longitudinal centerline of the probable touchdown area. The angle of the camera lens axis relative to the runway centerline is determined from this data and is essential for the analysis of the film. With the camera located and aligned in the above manner, the 50 mm lens is installed. This lens includes the complete normal approach and a reasonable amount of overshooting of the probable touchdown area.

A camera speed is selected that gives satisfactory results with the existing lighting conditions. Whenever possible, the highest camera speed (100 frames per second) is used in order to obtain a more accurate time base and a closer determination of wheel touchdown. The timer is placed in front of the camera so that the dial image and number plates are photographed in the lower corner of the film frame. For safety reasons, both the timer and camera are operated by remote control during actual landings.

Film Analysis

The analysis consists of taking certain measurements from a projected film record to obtain the space time data of the flight path of an airplane during the approach to a landing up to and

including the wheel touchdown. The data is entered into a standard form for the calculation of sinking speed, vertical acceleration and horizontal speed at touchdown. A sample calculation sheet and a description of the film measurements are presented in Appendix I.

It has been determined that data from 12 film frames prior to and including the initial main wheel contact is sufficient to obtain sinking speed, vertical acceleration, and horizontal speed during landing. The frames are read at equally spaced time intervals of .02 to .05 second. The selection of the time interval is dependent upon the framing speed of the camera during the filming of the landing being analyzed.

It must be pointed out that the time of initial wheel contact or touchdown, as used in the photographic method, is taken as the time when the wheels touch the runway minus .10 second. Therefore, the sinking speeds and accelerations obtained with this method correspond to those of an instant just prior to the touchdown while the airplane is still in the air.

SECTION IV

REDUCTION OF DATA

Wing Span Method

The space-time data obtained from the measurements of film records cannot be readily used to obtain a true space-time curve of the airplane during the relevant time period of a landing. The reason for this is that the scalar relationship between displacements on a coplanar reference frame on the film plane and true displacements on a parallel plane in the space is not known. Therefore, it is necessary to obtain a coefficient of relationship between film displacements and actual displacements. This coefficient or scale factor (S.F.) is defined by the following expression:

$$S.F. = \frac{S'}{w_i} \quad (\text{Ref. } 1) \qquad (1)$$

where:

S' = True calculated foreshortened wing span (or flap span) in feet.

w_i = Projected image foreshortened wing span (or flap span) in inches.

It is assumed, in order to be able to calculate the true foreshortened span, that the airplane longitudinal centerline remains parallel to the runway during landing. Then the true foreshortened span can be calculated by first determining the angles formed by the lines of sight from the camera to the wing tips with the flight path

of the airplane.

The angle of any given line of sight (LOS) can be obtained from the triangle formed by the lens axis, the line of sight, and the displacement normal to the lens axis of the point image on the film (Fig. 4). This angle, α, is equal to:

$$\operatorname{Tan} \alpha = \frac{a}{F} \qquad (\text{Ref. } 1) \qquad (2)$$

where:

a = Displacement of the point image on the film.

F = Focal length of the camera lens.

The knowledge of the angle between a line of sight and the lens axis is not sufficient to be able to establish $\overline{BC}$ (the displacement of actual point in this space) since neither $\overline{AB}$ nor $\overline{AC}$ are known (Fig. 4). However, if the length of an actual object is used in place of a single point, the foreshortened length can be established at any instant of the motion of the object from the relationship between the true length of the object, the angle that the camera lens axis forms with the line of motion of the object, and the angles that the lines of sight to the tips of the object form with the line of motion (Fig. 5). This relationship is as follows:

$$S' = \frac{S}{2}\left(\frac{\cos\theta_1}{\cos(\theta_0-\theta_1)} + \frac{\cos\theta_2}{\cos(\theta_0-\theta_2)}\right) \quad (\text{Ref. } 1) \quad (3)$$

or:

$$S' = \frac{S}{2}(\text{cosine function}) \qquad (4)$$

where:

$\frac{S}{2}$ = True semi-span in feet.

θ_0 = Angle between lens axis and C. L. runway.

θ_1 = Angle between the LOS of one of the wing or flap tips and the centerline of the runway.

θ_2 = Angle between the LOS of the other wing tip and the centerline of the runway.

After establishing the angles between the span tips and the lens axis with equation (2), both θ_1 and θ_2 can be derived geometrically (Fig. 5) and their cosines introduced in equation (3) to obtain the true foreshortened span.

When a large number of landings are being analyzed, it is convenient to make use of a nomograph (Fig. 6) that enables obtaining

the "cosine function" of equation (3) for any instant of the landing flight path of any type airplane. A single nomograph can be used in the manner described above, provided that the location, orientation, and focal lens of the camera are not changed throughout the filming of the landings. In the nomograph, the expression:

$$d = \frac{X_1 + X_2}{2W} \quad (\text{Ref. } 1) \tag{5}$$

denotes the ratio of the distance of the mid-point of the foreshortened span from the vertical edge of the projected film to the width of the projected film (Fig. 6). The ratio is constant for any given instant of a landing regardless of whether the distances and width of film are taken from the film projection or the film itself at that instant. Moreover, this ratio serves the purpose of locating the midpoint of the span along the line resulting from the projection of the flight path on the horizontal plane. Different magnitudes of the ratio correspond to different foreshortened spans during any given landing. Ratios of equal magnitude, each of which corresponds to different landings with the same airplane, correspond to the same magnitude of the foreshortened span.

In order to construct the nomograph, it is necessary to evaluate equations (3) and (5) for only two landings. The lines that join the corresponding values of d and the "cosine function" for each of the landings intersect at a point (Point "A" in Fig. 6). For any subsequent landings, it is only necessary to find d, draw a straight line through d and point "A" and read the cosine function. When a different airplane is used, the same nomograph can be utilized by just finding a new point "A".

Because of the smallness of the variation in magnitude of the foreshortened span throughout any given landing (during the relevant time period of the photographic method) it is adequate to determine the foreshortened span for only one frame of a film and use it as a constant for the determination of the space-time curve of a landing.

The computation of the true foreshortened span is illustrated on the sample calculation sheet in Table III, Appendix I.

<u>Sinking Speed and Acceleration</u> (Ref. 5)

For the purpose of determining the sinking speed at touchdown, it is necessary to know the true height of the airplane at various discrete instants during the time period prior to the landing. The true height at any instant is defined by the following expressions:

$$H = \frac{h_{i(ave)}\, S'}{W_i} \tag{6}$$

$$R = \frac{h_{i(ave)}}{W_i} = f(time) \tag{7}$$

$$H = RS' \quad (8)$$

where:

$h_{i(av)}$ Image average wheel height as measured from any film frame during a landing (including the frame where touchdown occurs), using as a reference axis a horizontal plane represented on the film frame by a horizontal line passing through the center of each frame

H = True average wheel height

R = Function of time

It has been found that the parabola

$$R = a + bt + ct^2 \quad (9)$$

will represent with reasonable accuracy the space-time curve of an airplane during landing. Therefore, the true height of the airplane above a horizontal reference line at any instant of landing may be expressed by:

$$H = S'(a + bt + ct^2) \quad (10)$$

Since measurements are taken from the film at equal time intervals, when an arbitrary time scale is assumed, it is possible to determine the magnitude of the constants of equation (9) by means of the method of least squares. Therefore, by assuming Δt equal to one second, the domain of the time scale from 0 to 12 seconds, and t_c equal to 12 (the time of initial wheel contact), the residual equations (one for each observation) are:

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ \cdot \\ \cdot \\ V_{12} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 2 & 4 \\ 1 & 3 & 9 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ 1 & 12 & 144 \end{bmatrix} \begin{bmatrix} a' \\ b' \\ c' \end{bmatrix} - \begin{bmatrix} R_1 \\ R_2 \\ R_3 \\ \cdot \\ \cdot \\ R_{12} \end{bmatrix} \quad (11)$$

The following three normal equations may then be written by following the standard reduction procedure given in Ref. 4:

$$\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} = [A] \begin{bmatrix} a' \\ b' \\ c' \end{bmatrix} - [B] \{R_i\} \quad (12)$$

where:

$$[A] = \begin{bmatrix} 12 & 78 & 650 \\ 78 & 650 & 6084 \\ 650 & 6084 & 60710 \end{bmatrix} \qquad (13)$$

and

$$[B] = \begin{bmatrix} 1 & 1 & 1 & 1 & \cdot & \cdot & \cdot & 1 \\ 1 & 2 & 3 & 4 & \cdot & \cdot & \cdot & 12 \\ 1 & 3 & 9 & 16 & \cdot & \cdot & \cdot & 144 \end{bmatrix} \qquad (14)$$

The coefficients a, b and c refer to the true time scale and a^1, b^1, and c^1 to the arbitrary time scale. Hence,

$$\begin{bmatrix} a' \\ b' \\ c' \end{bmatrix} = [A]^{-1}[B]\{R_i\} \qquad (15)$$

Sinking speed can be obtained from:

$$V_v = \frac{dR}{dt} \times \frac{12S'}{t_e} \text{ in ft./sec.} \qquad (16)$$

or:

$$V_v = \frac{12S'}{t_e}(b + 2ct) \qquad (17)$$

where

$$\frac{12}{t_e} = \frac{\text{Arbitrary 12 second interval}}{\text{True total elapsed time}}$$

a factor which relates the parabola based on the arbitrary scale and the one based on the true time scale.

At wheel contact (touchdown) t = 12, therefore:

$$V_v = \frac{S'}{t_e}(12b + 288c) \qquad (18)$$

or

$$V_v = \frac{S'}{10t_e}(120b + 2880c) \qquad (19)$$

An arbitrary factor of 10 is introduced in equation (18), which can be also written as:

$$V_v = \frac{S'}{10t_e}[0 \quad 120 \quad 2880][A]^{-1}[B] \qquad (20)$$

After evaluating $[A]^{-1}[B]$ in equation (20) and performing the operations indicated

$$V_v = \frac{S'}{10t_e}(13.52R_1 + 4.46R_2 - 2.61R_3 - 7.70R_4 - 10.82R_5 - 11.96R_6 - 11.12R_7 - 8.30R_8 - 3.51R_9 + 3.27R_{10} + 12.02R_{11} + 22.75R_{12}) \qquad (21)$$

Similarly, acceleration is:

$$A_v = \frac{d^2R}{dt^2} \times \frac{S'}{(t_e/12)^2} \quad \text{in ft./sec.} \qquad (22)$$

or

$$A_v = \frac{d^2R}{dt^2} \times \frac{S'}{32.2(t_e/12)^2} \quad \text{in g's} \qquad (23)$$

and introducing an arbitrary factor of 100

$$A_v = \frac{d^2R}{dt^2} \times \frac{100\,S'}{(100)(32.2)(t_e/12)^2} \qquad (24)$$

or

$$A_v = \frac{S'}{100\,t_e}\left(\frac{14400}{32.2}\right)(2c) \qquad (25)$$

at first wheel contact. By substituting c

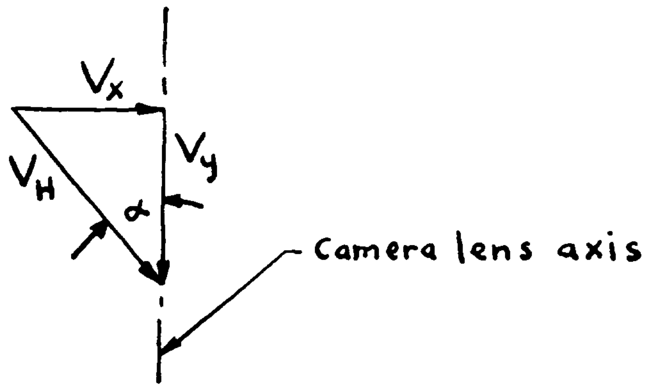
$$A_v = \frac{S'}{100\,t_e}\left(\frac{28800}{32.2}\right)[A]^{-1}[B] \qquad (26)$$

or

$$A_v = \frac{S'}{100\,t_e}\big(12.29R_1 + 5.59R_2 + .22R_3 - 3.80R_4 - 6.48R_5 - 7.82R_6 - 7.82R_7 - 6.48R_8 - 3.80R_9 + .22R_{10} + 5.59R_{11} + 12.29R_{12}\big) \qquad (27)$$

Horizontal Speed at Wheel Contact (Ref. 1)

Let V_x be equal to the horizontal speed component (normal to the camera lens axis) of the airplane during landing and V_y the horizontal speed component of the same along the lens axis.



The resultant, V_H, is equal to the horizontal speed of the airplane along its flight path. In order to establish the normal and parallel velocities at any instant of the flight path, it is first necessary

to determine the true space-time curve of the horizontal flight during the desired time interval of the landing. This is accomplished by measuring on the projected film the distance of a predetermined point on the airplane from the vertical edge of the film (X_3) and the width of the projected film (W). With these measurements it is possible to obtain

$$D = S'\left(\frac{X_3 - \frac{W}{2}}{w_i}\right) \tag{28}$$

which is equal to the distance of a point on the airplane from the lens axis, and

$$L = \frac{S'F'}{w_i} \tag{29}$$

equal to the distance of the same point on the airplane along the lens axis from the plane of the film in the camera at the time of filming.

Since both D and L are different in magnitude on each frame of the film record and assuming that no horizontal acceleration occurs during the time interval of the observations, the following equations may be written:

$$\begin{aligned} D_1 &= a + bt_1 \\ D_2 &= a + bt_2 \\ &\cdots\cdots \\ D_6 &= a + bt_6 \end{aligned} \tag{30}$$

Solving for b by the method of averages

$$b = \frac{\sum_1^3 \frac{X_3 - W/2}{w_i} - \sum_4^6 \frac{X_3 - W/2}{w_i}}{\sum_4^6 t - \sum_1^3 t} \tag{31}$$

Also, the horizontal speed of the airplane normal to the lens axis is:

$$\frac{dD}{dt} = S'b \tag{32}$$

or:

$$V_x = S'b \tag{33}$$

By substituting:

$$V_x = S'\left[\frac{\sum_1^3 \frac{X_3 - W/2}{w_i} - \sum_4^6 \frac{X_3 - W/2}{w_i}}{\sum_4^6 t - \sum_1^3 t}\right] \tag{34}$$

Similarly

$$V_y = S'\left[\frac{F' \sum_1^3 \frac{1}{w_i} - F' \sum_4^6 \frac{1}{w_i}}{\sum_4^6 t - \sum_1^3 t}\right] \tag{35}$$

Hence,

$$\tan\alpha = \frac{\sum_{1}^{3}\frac{X_3}{w_i} - \sum_{4}^{6}\frac{X_3}{w_i}}{F'\left(\sum_{1}^{3}\frac{1}{w_i} - \sum_{4}^{6}\frac{1}{w_i}\right)} - \frac{W}{2F'} \qquad (36)$$

The horizontal speed of the airplane along its flight path (V_H), may then be obtained from the following expression:

$$V_H = \frac{V_y}{\cos\alpha} \text{ in ft./sec.} \qquad (37)$$

or:

$$V_H = \frac{.5921\,V_y}{\cos\alpha} \text{ in knots} \qquad (38)$$

Statistical Method

The relative frequency of sinking speeds and horizontal landing speeds are presented in the form of cumulative probability curves. The probabilities are obtained by means of Karl Pearson's Areas of the Standardized Type III Function

$$y = y_0\left(1 + \frac{\alpha}{2}t\right)^{\frac{4}{\alpha^2}} e^{-\frac{2}{\alpha}t} \quad (\text{Ref. } 3) \qquad (39)$$

and the method described in Ref. 2.

The Pearson Type III probability curves form a three parameter family. The parameters for a particular distribution are determined from the arithmetic mean value, the standard deviation, and the coefficient of skewness of the distribution. The actual computation of these curves is somewhat involved, the reason for which in Ref. 2, for convenience, curves within the range of skewness expected in the analysis of V-G data were plotted against "t", the so-called "standard statistical scale". In this manner, it is only necessary to determine the skewness and the range of "standard statistical scale" of a particular distribution, and then interpolate between the pre-plotted curves to obtain probability.

However, to avoid the errors that creep into graphical interpolations, the actual method of calculation of probability has been used for the analysis of the Berlin Airlift data.

For example, the cumulative probability curve of a group sinking speed data can be determined by first obtaining the mean value, the standard deviation, and the coefficient of skewness of the distribution from the following formulas:

$$\overline{V_v} = \frac{1}{N}\sum V_v \qquad (40)$$

$$\sigma_v = \sqrt{\frac{1}{N}\sum\left(V_v - \overline{V_v}\right)^2} \qquad (41)$$

$$\alpha_v = \frac{1}{N\sigma_v^3}\Sigma(V_v - \bar{V}_v)^3 \qquad (42)$$

After this, the limits of the range of the "standard statistical scale" of the particular distribution may be obtained from:

$$t_a = \frac{V_{v(max)} - \bar{V}_v}{\sigma_v} \qquad (43)$$

$$t_b = \frac{V_{v(min)} - \bar{V}_v}{\sigma_v} \qquad (44)$$

By interpolation on the three-parameter table (probability of equaling or exceeding versus "standard statistical scale" for discrete values of skewness) resulting from the solution of Pearson's Type III Function (Eq. 38) (Ref. 3), the probability for values of the "standard statistical scale" may be obtained. The probabilities thus obtained are associated with discrete values of sinking speed determined from the equation:

$$V_v = \sigma_v t_x + \bar{V}_v \qquad (45)$$

where t_x may have any value within t_a and t_b.

SECTION V

RESULTS AND DISCUSSION OF DATA

General

Prior to the analysis, a review of each landing was made to determine its suitability for analysis. The bases for the selection of a suitable landing were the clarity and distinctiveness of the projected film image, and the magnitude of the scale factor of the same. It was considered that the airplane image size of a landing with a scale factor of 39.1 ft/inch was too small to enable reading with accuracy the required measurements of each film frame. It was found, as a result of this review, that only 275 landings were analyzable, of which 187 took place at Tempelhof and 88 at Rhein-Main.

The results of the analysis of the individual landings at Tempelhof and Rhein Maih, respectively, are presented in Appendix I. They consist of the sinking speed, horizontal landing speed, acceleration and angle of roll at contact. Also the weather conditions prevailing during each landing (ceiling, visibility, temperature, and wind direction and velocity).

Correlation Between Cross-Wind and Sinking Speed

An attempt was made to determine whether or not cross-wind during landing has any effect on the magnitude of the sinking speed at wheel contact. It was considered that if any correlation exists, it would be evidenced in a plot of the horizontal wind component normal to the runway centerline versus sinking speed.

For correlation purposes, the sinking speeds of the Tempelhof cross-wind landings have been used. The magnitude of the cross-wind component varied from a minimum of 5.00 MPH to a maximum of 14.27 MPH. A plot of cross-wind component versus sinking speed is shown on Figure 7.

The scatter of the data points of Figure 7 is such that no simple relationship between cross-wind and sinking speed can be discerned from a visual inspection. However, it can be noticed that the majority of the sinking speeds are segregated in groups and each group corresponds to a different component of cross-wind velocity. As a result, it was possible to establish the average sinking speed of each group of landings of equal cross-wind velocity (identified by crosses on Figure 7). Therefore, the line joining these average points is an approximate representation of the curve of best fit through the data points. No reasonable or practical trend can be discerned from the resulting saw-toothed shaped curve.

Sinking Speed

During the landings of the Berlin Airlift the airplanes were very uniformly loaded. As a results, it has been established that the average landing weights of the C-54 type aircraft used during this operation were 67,900 pounds at Tempelhof and 46,800 pounds at Rhein-Main, with an average variation of plus or minus 250 pounds.

It was expected that, as a result of the difference in landing weights, the ranges and frequency distributions of sinking speeds at Tempelhof and Rhein-Main would be significantly different. However, an inspection of the sinking speeds has shown that the maximum and minimum magnitudes were -7.23 and -.05 feet per second at Tempelhof, and -6.43 and -.71 at Rhein Main. Considering the number of observations used for each case (183 Tempelhof landings and 87 Rhein-Main landings), the difference in ranges is not significant.

Two frequency polygons, one for the Tempelhof and another for the Rhein-Main sinking speeds, are shown on Figures 8 and 9 respectively. A comparison of these two polygons is shown on Figure 10, where it may be seen that in spite of the difference in landing weight, the characteristics of the two polygons are very similar. For instance, the standard deviation of the Tempelhof distribution is ± 1.40 feet per second from the mean (-2.55 ft. per second) as compared to a standard deviation of ± 1.21 feet per second from the mean (-3.09 ft. per second) in the Rhein-Main distribution. From a statistical viewpoint, the difference between these two deviations is not large enough to be of any significance. Equally small is the difference between the coefficients of skewness of the two distributions, +.72 and +.44, respectively.

To simplify the interpretation and possible applications of the frequency distribution of sinking speeds, two curves of probability of equaling or exceeding versus sinking speed are shown on Figures 11 and 12 pertaining to the landings at Tempelhof and Rhein Main, respectively.

Horizontal Landing Speed

The horizontal touchdown speeds that have been obtained during this investigation were plotted in the form of curves of probability of equaling or exceeding versus the ratio of the true air speed at touchdown to design stalling speed (Figures 13 and 14).

The design stalling speed of the above ratio has been 112 MPH for a maximum landing weight of 70,000 pounds at sea level without use of flaps.

As in the case of the sinking speeds, the frequency distributions of horizontal true landing airspeeds for heavy weight and light landing weight conditions are very similar. For these two landing weight conditions, the respective ranges, mean values, standard deviations, and coefficients of skewness are 70 MPH-133 MPH and 75 MPH-123 MPH, 100 MPH and 96.5 MPH, 11.5 MPH and 8 MPH, and .56 and .67.

Acceleration

Since the wheel contact is considered to take place at an instant just prior to the touchdown while the airplane is still in the air, it has been assumed that at this instant the airplane is a rigid body subjected to translational acceleration, and that rotational accelerations of the body are negligible. It can be stated then, on the basis of this assumption, that the acceleration of the main landing wheels measured by means of the photographic method is equal to the acceleration of the center of gravity of the airplane. The acceleration thus obtained has been considered equal to the increment wing load factor at touchdown.

In accordance with the above assumption, the accelerations in g's resulting from this analysis have been added algebraically to 1.0 to obtain wing load factor at touchdown. Downward vertical accelerations are considered to be negative and upward accelerations (decelerations) positive. The resulting wing load factors are plotted against sinking speed on Figures 15 and 16 for the heavy weight and light weight conditions respectively. A definite relationship between wing load factor and sinking speed is shown in these plots. In general, high values of sinking speed are associated with low positive wing load factors and vice versa.

The profusion of scatter of the data points in Figures 15 and 16 made it necessary to find a line of best fit through these points (solid lines) by the method of least squares. A measure of the degree of scatter of load factor about the lines of best fit resulted in a "standard error estimate",

$$S = \sqrt{\frac{\Sigma d^2}{N}}, \tag{46}$$

equal to $\pm$ .12 for the heavy weight condition and $\pm$ .09 for the light weight condition. The band enclosed by $\pm$ S includes 68% of the observations. In equation (46) d^2 represents the square of the difference between an actual value of load factor and a value calculated with the equation of the line of best fit and N the number of observations.

It has been noted that in both the heavy and light weight conditions, approximately 70% of the sinking speeds correspond to a load factor of 1.0 or less.

Accuracy and Statistical Considerations

The results of the photographic method include "systematic errors" and "accidental errors". In general, "systematic errors" are classified as those produced by adjustments of the equipment, personal equations of the observers, etc. This can usually be remedied by careful checking of the equipment and proper indoctrination of the personnel involved. "Accidental errors" are always small; they result from fluctuations of the observational ability of the operators and other sources, and their evaluation is subject to mathematical treatment.

The majority of the "systematic errors" of the method are minimized by careful control and adjustment of the sources of error. It has been determined that the absolute cumulative value of "systematic errors" never exceeds 50% of the mean "accidental errors" of linear and angular measurements obtained from a projected film (Ref. 1).

The magnitude of "accidental errors" of the method depends not only on fluctuations of observational ability, but also on the distance of the point of touchdown of the airplane from the recording camera. The farther this point is from the camera, the smaller the

size of the airplane image and airplane displacements on the film. This reduction brings about larger relative "accidental errors" on measurements taken from the film projection. It has been determined that the probable errors of sinking speed, acceleration, and horizontal landing speed are ± 1.8 feet per second, ± 2.4 feet per second per second and ± 7.0 MPH, respectively, for the farthest landing analyzed (approximately 1100 feet from the camera). When the touchdown distance is approximately 300 feet from the camera, the probable errors of sinking speed acceleration, and horizontal landing speed are ± .5 feet per second, ± 1.0 feet per second per second and 2.3 MPH, respectively. The above probable errors consist of probable "accidental errors" plus a constant value that represents a composite "systematic error" of the photographic method (Ref. 1).

In both the heavy weight and light weight conditions, the distances of the landings from the camera varied between 300 to 1100 feet. Throughout this range, the landings were distributed uniformily. No significant concentration of landings took place at any given distance.

Since the probable errors increase with the distance of the initial wheel touchdown from the camera, if an equally large and equally distributed group of sinking speeds or accelerations were to take place at discrete intervals along the range of distances, then within each group there would be a sub-group of sinking speeds or accelerations equal to or smaller than their respective probable errors. Moreover, the total amount and individual magnitude of distinct sinking speeds or accelerations of the sub-groups would increase with distance, to such an extent, that on far groups (300 feet or more from the camera) it would be erroneous to consider the data of individual landings irrespectively of those of other landings. Therefore, the data of landings at various distances (beyond 300 ft. from the camera) can only be used collectively to express a statistical trend. Since measurement errors are as likely to enter in a positive sense as in a negative sense, the statistical trends represent a close approximation of trends obtained with observations devoid of error.

SECTION VI

CONCLUSIONS

On the basis of the results of this analysis, the following conclusions appear:

Pilot's All-Controlling Effect

In order to simplify the interpretation of the subject analysis and the study of future analyses, it has been assumed that the pilot's

ability is the all-controlling variable that determines the speed level of a landing. This assumption is reasonable. It can be easily understood that if it were planned to conduct a statistical study of landing velocities (sinking speed, and horizontal landing speed) in which the effect of physical variables incidental to landings (landing weight, weather, type of aircraft, etc.) on the magnitude of each one of the speeds had to be obtained, the study would entail an extremely difficult task. The cost and time of performance of the task would not be commensurate with the technical value of the results.

However, a certain amount of refinements or breakdowns have to be made if the statistical studies of landing velocities are to serve a practical engineering purpose. It has been considered that the only logical and practical breakdown should be the grouping of data according to the mediums on which landings are performed, the mediums being carrier, land, and sea. Then, the observations within each medium, such as those of sinking speed, can be considered to be homogeneous events, and the difference in magnitude of the observations, the results of the pilot's all-controlling effect.

In summary, it has been assumed that there is a distinct population of sinking speed and landing horizontal speed for each medium (carrier, land and sea). Moreover, that it is practical to neglect the effect of physical variables incidental to landings within each medium. But that in the future, statistical studies to establish the population of sinking speeds and horizontal speeds will be conducted in various carriers, airports, etc., so that the ability of pilots to cope with the various physical variables is well represented in the studies.

On the basis of the preceding assumption, the results of this analysis have been interpreted as follows:

Correlation of Cross-Wind and Sinking Speed

The lack of effect of cross-wind on the magnitude of sinking speed suggests that the number of observations for the attempted correlation may have been insufficient, or that, on the average, the pilot's all-controlling ability may have nullified the effect if there is any.

This attempt to correlate cross-wind and sinking speed serves as an illustration of the magnitude of the task that would be faced if the various physical variables were to be correlated with sinking speed or horizontal landing speed.

Sinking Speed

Any conclusions as to the maximum value and population of sinking speeds based on these results alone would be premature. The landings on which this analysis is based represent a very limited amount of data to enable statistical inference.

Therefore, the two samples of sinking speeds presented on Figures 11 and 12, for heavy and light weight conditions, respectively, have been looked upon as accessory data. On the basis of the pilot's all controlling effect, the difference between the two samples has been considered as the normal variation expected when sampling a single population rather than the effect of the landing weight difference.

In the absence of more universal data, the two samples of sinking speeds can be used for the selection of design limit sinking speed of landbased airplanes provided, of course, that a reasonable amount of conservatism is used.

Horizontal Landing Speed

The conclusions concerning the universality and usage of the sinking speed data are equally applicable to the horizontal landing speeds. It should be noted that when the functional relationship between landing gear dynamic spin-up forces and horizontal landing speed is known, the probability curves of horizontal landing speeds (Figs. 13 and 14) can be used to represent the frequency of occurrence of the spin-up forces.

The fact that spin-up forces produce fore and aft landing gear oscillations is well known. Thus when the number and magnitude of the oscillations produced by a spin-up force have been established, experimentally or theoretically the frequency of occurrence of the spin-up force can be used to determine the frequency of occurrence of the oscillations. This information would prove valuable in establishing expectancy data for service landing gear drag loads which is required to approximate the fatigue life of landing gears and their support structure.

Wing Load Factor

The curves of wing load factor versus sinking speed (Figs. 15 and 16) embodying the acceleration measurements of the analysis represent reasonable approximations of actual wing load factors of C-54 aircraft during landing. The curves have been intended to serve only as indexes for comparing the relationship between wing load factor and sinking speed of different landbased airplanes. Data of this nature is useful in the selection of wing lift when the latter is simulated in translational drop tests of airplanes.

Photographic Method

The main advantage of the method, and doubtless an essential one, is the fact that it enables observing a large number of landings of different airplanes without requiring the installation of any equipment on the airplanes being observed. However, it has been considered that some minor revisions of the method should be effected to reduce the magnitude of errors in measuring the sinking speed and acceleration of individual runway type landings. An increase in the accuracy of these measurements will result in a reduction of the number of observations required for adequate sampling. Some suggestions with regard to the revisions are given under Recommendations (Section VII of the body of this report.).

SECTION VII

RECOMMENDATIONS

Photographic Method

Inasmuch as the source of large "accidental errors" of the photographic method lies in the magnitude of the scale factors of projected films, it is suggested that for reducing these errors, the magnification of the film projections be adequately increased. It has been considered, of course, that the increase in magnification may be limited by the amount of fuzziness of the images. However, this limitation could be largely reduced by the use of small grain films such as Panatomic or Super X-Panchromatic.

In addition to using larger magnification, the general accuracy of the method could be improved when used for runway type landings, by using two or more cameras for filming as specific cases may require. In this manner, a large portion of a landing area would be covered by the camera so that, within this portion, any landing takes place reasonably close to the camera. This would insure obtaining a small scale factor which would in turn result in smaller "accidental errors".

Obtaining a Population of Sinking Speeds

The need for more sampling cannot be overemphasized. It will be recalled from the discussion in the preceding section (VI) concerning the population of sinking speeds, that the two samples described herein are scant data for the extension of the results to cases not included in the samples. The same is probably applicable to the population of sinking speeds of carrier-based airplanes and seaplanes. As a result, questions arise as to the method of observation, number of observations, and degree of representativeness of future sampling.

For sampling purposes, the photographic method will serve efficiently and practically provided that the revisions indicated above are adopted when used for filming runway type landings. It has been already used successfully for filming carrier landings (Ref. 1). However, its applicability to water-type landings has not yet been evaluated.

Assuming that this method will be used for a large scale survey of sinking speeds of landbased airplanes, it has been estimated that a minimum of 15,000 landings will be required to include in the sampling all the relevant physical variables and pilot's techniques. With regard to the representativeness of the survey, a reasonable variation of the following physical factors incidental to landings should be included:

1. Airplanes

For simplicity, only a reduced number of airplanes should be observed provided that the following weight categories are reasonably represented in the observations:

a. Heavy
b. Medium
c. Light

2. Airports

For economy, only airports of high landing density should be selected. For adequate sampling, the airports selected should include a reasonable variation of the following factors:

a. Altitude above sea level.
b. Runway length.
c. Height and distance from the end of the runway of obstacle to be cleared during landing.

Excluding landing density, the selection of airports on the basis of the above factors can be simplified by expressing the airport properties in a correlation of

$$\frac{\text{Runway Length}}{\text{Altitude Above S.L.}} \quad \text{Versus} \quad \frac{\text{Obstacle Height}}{\text{Obstacle Dist. from Runway}}$$

3. Weather

The sampling should include the seasonal weather variations of each airport selected. In this manner, a wide range of the following weather elements will be represented in the samples:

a. Ceiling.
b. Visibility.
c. Wind Direction and Velocity.
d. Ambient Temperature.

Criterion for Selection of Sinking Speed

Arriving at definite criteria on the selection of sinking speeds for design purposes will be justifiable only when the knowledge of the populations of sinking speeds has been obtained. Even then it will be necessary to distinguish that the knowledge of the populations has merely quantitative significance. By itself, the statistical data does not have qualitative value since it cannot be said that a magnitude of sinking speed is better than another because it has a lower probability of occurrence or vice versa.

However, it is possible to make a magnitude of sinking speed represent a degree of quality by determining its (the sinking speed) interaction with the basic elements of the general policy governing the design of a specific airplane type. Viewed in this manner, the process for selecting a reasonable design limit sinking speed is analogous to that of determining the limits of confidence (or allowable manufacturing tolerances) of a machine part. In the latter case, the limits of confidence represent

a compromise between facts (frequency distribution of part sizes) and policy (cost of manufacture, "scrappage", and strength). Analogously, the selection of a sinking speed should represent a compromise between:

1. Facts

   The probability of occurrence of sinking speeds, and

2. Policy

   The degree of expendability assigned to the airplane, its operational purpose, operational efficiency, and cost manufacture.

SECTION VIII

REFERENCES

1. R. F. Kelly, M.E. Soennichsen and J. A. Robb. The Standard N.A.E.S. Photographic Method for Determining Airplane Behavior and Piloting Technique During Landings. Navy Department, Bureau of Aeronautics Report No. ASL NAM DE-210.1. September 1948. (Unclassified, English)

2. A. M. Peiser and M. Wilkerson. A Method of Analysis of V-G Records from Transport Operations. N.A.C.A. Report No. ARR L 5J04. November 1945 (Restricted, English).

3. Harry C. Carver. Statistical Tables. Ann Arbor, Mich., Edward Brothers, Inc. Lithoprinters, 1940. pp 1-61. (Unclassified, English).

4. J. B. Scarborough. Numerical Mathematical Analysis. The Johns Hopkins Press, 1949. pp 364-365 (Unclassified, English).

5. Letter No. 62048 from Bureau of Aeronautics to GLM dated 9 Aug. 1950.

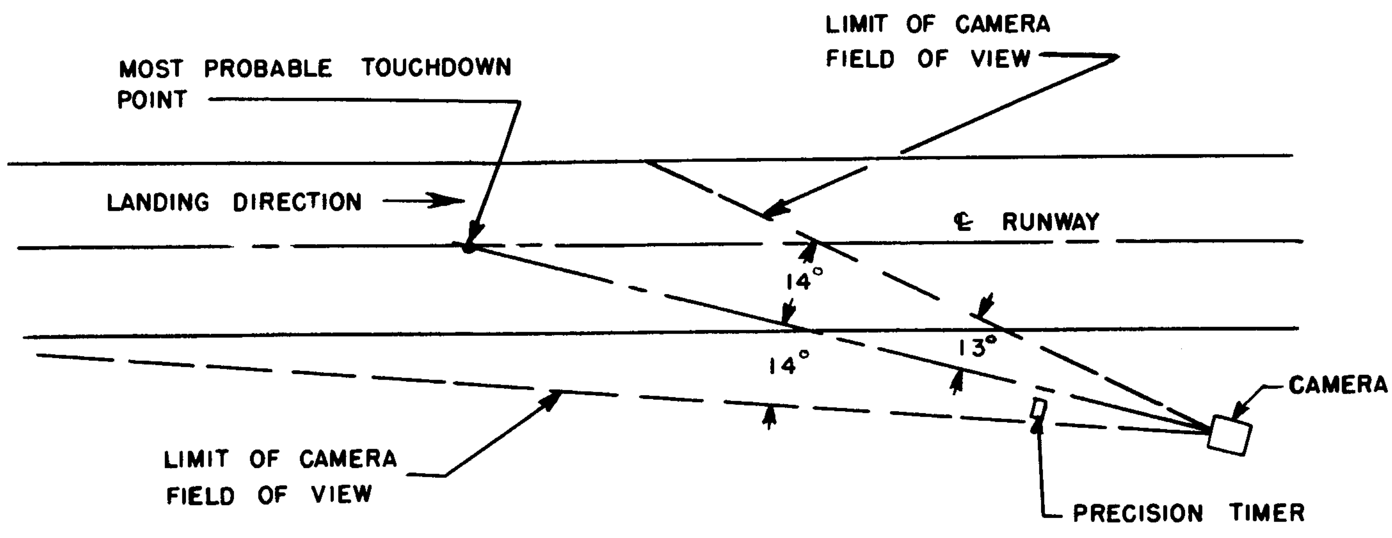


FIGURE NO 1

EQUIPMENT SET UP TO RECORD RUNWAY LANDINGS

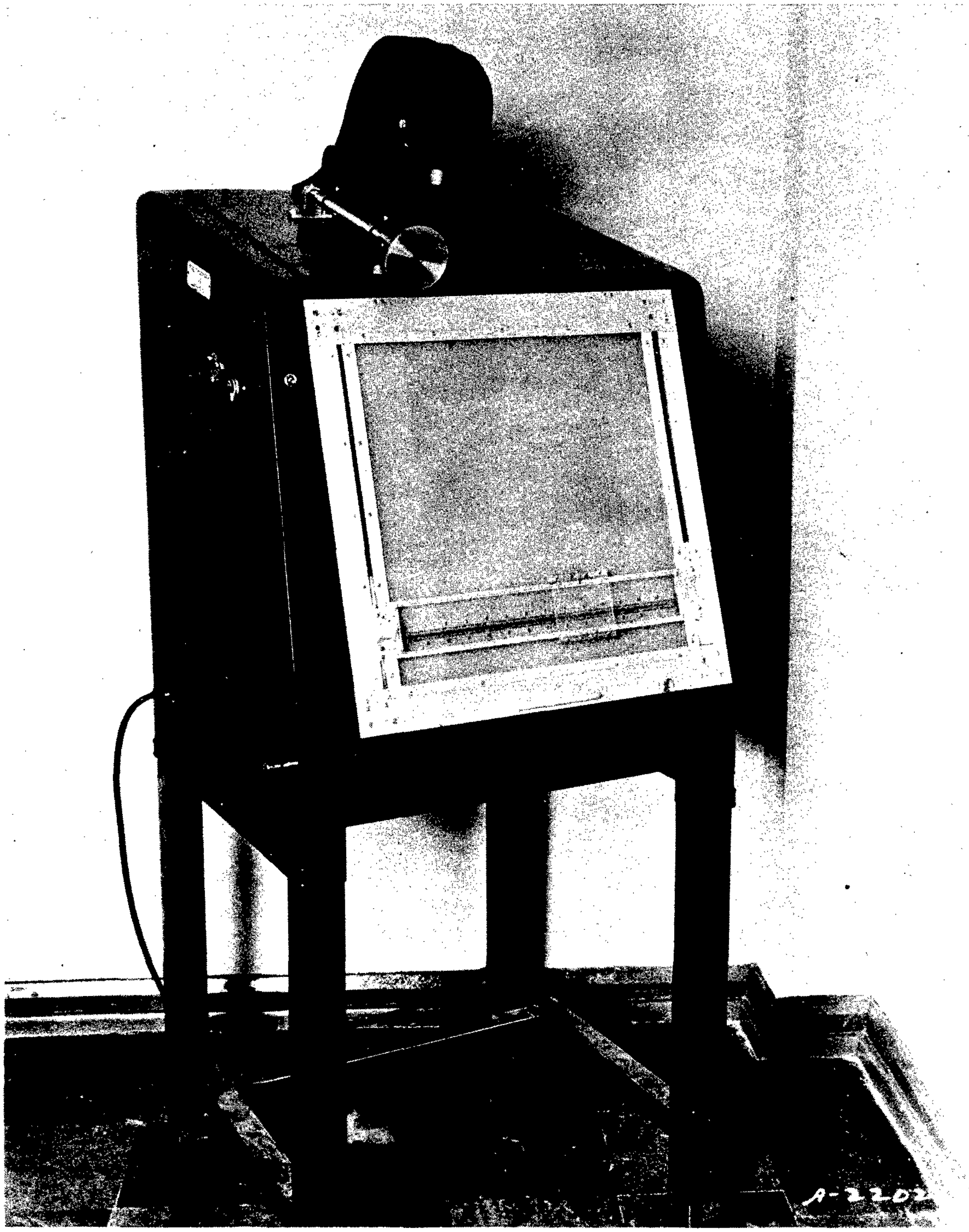


Figure No. 2 Recordak Viewer

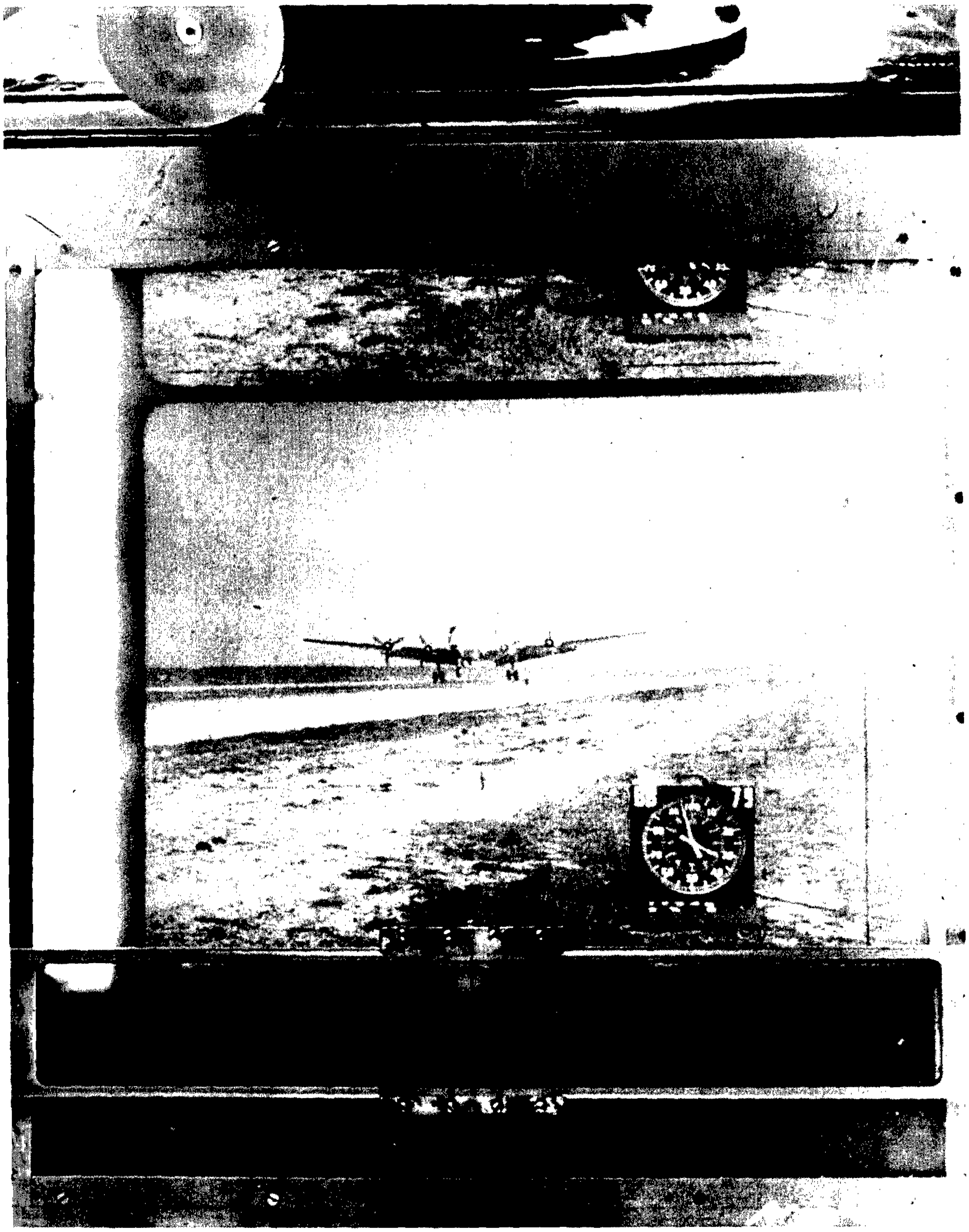


Figure No. 3 Landing Record Projected on Recordak

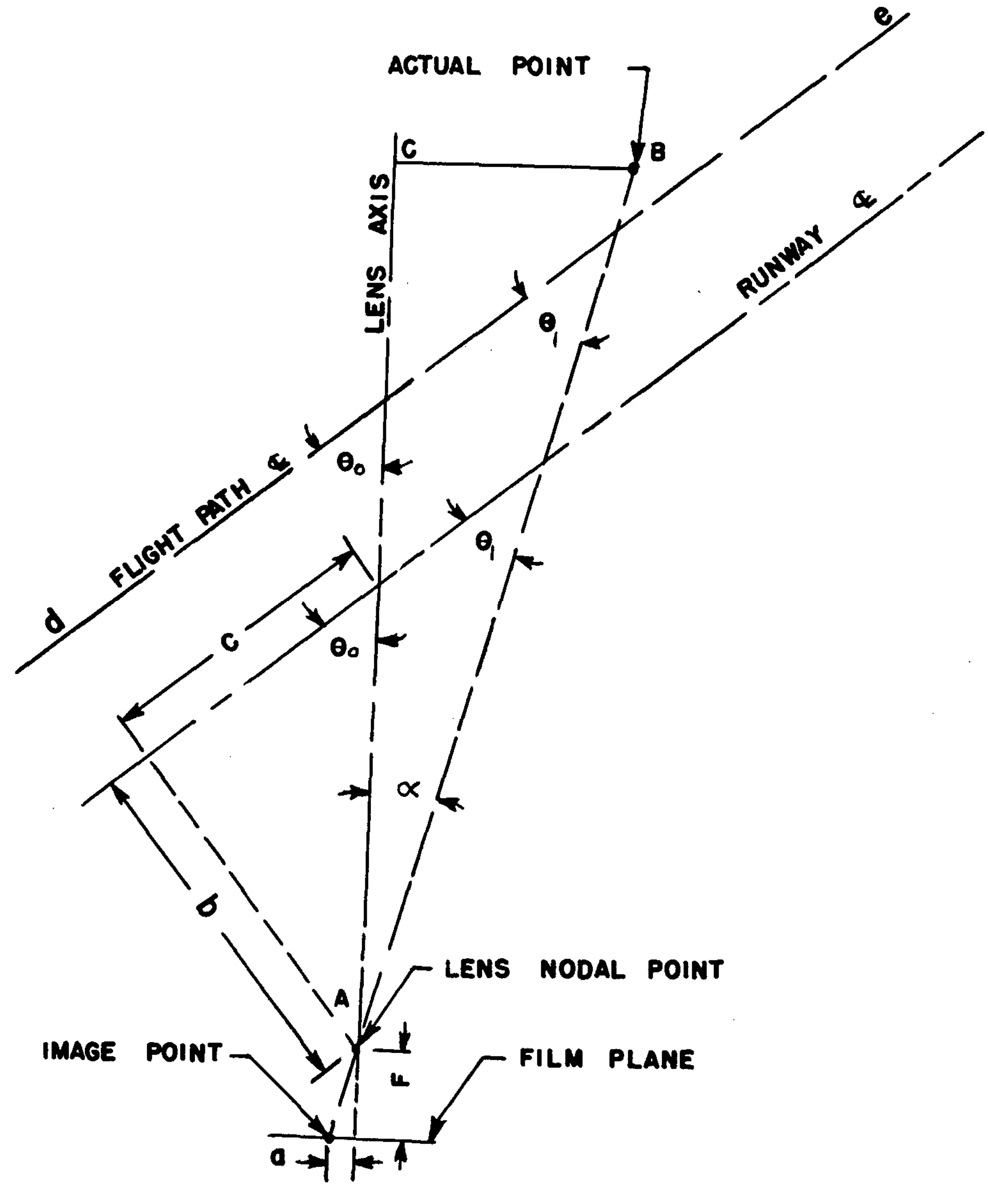


FIGURE NO 4

DIAGRAM OF ANGLE OF LINE OF SIGHT

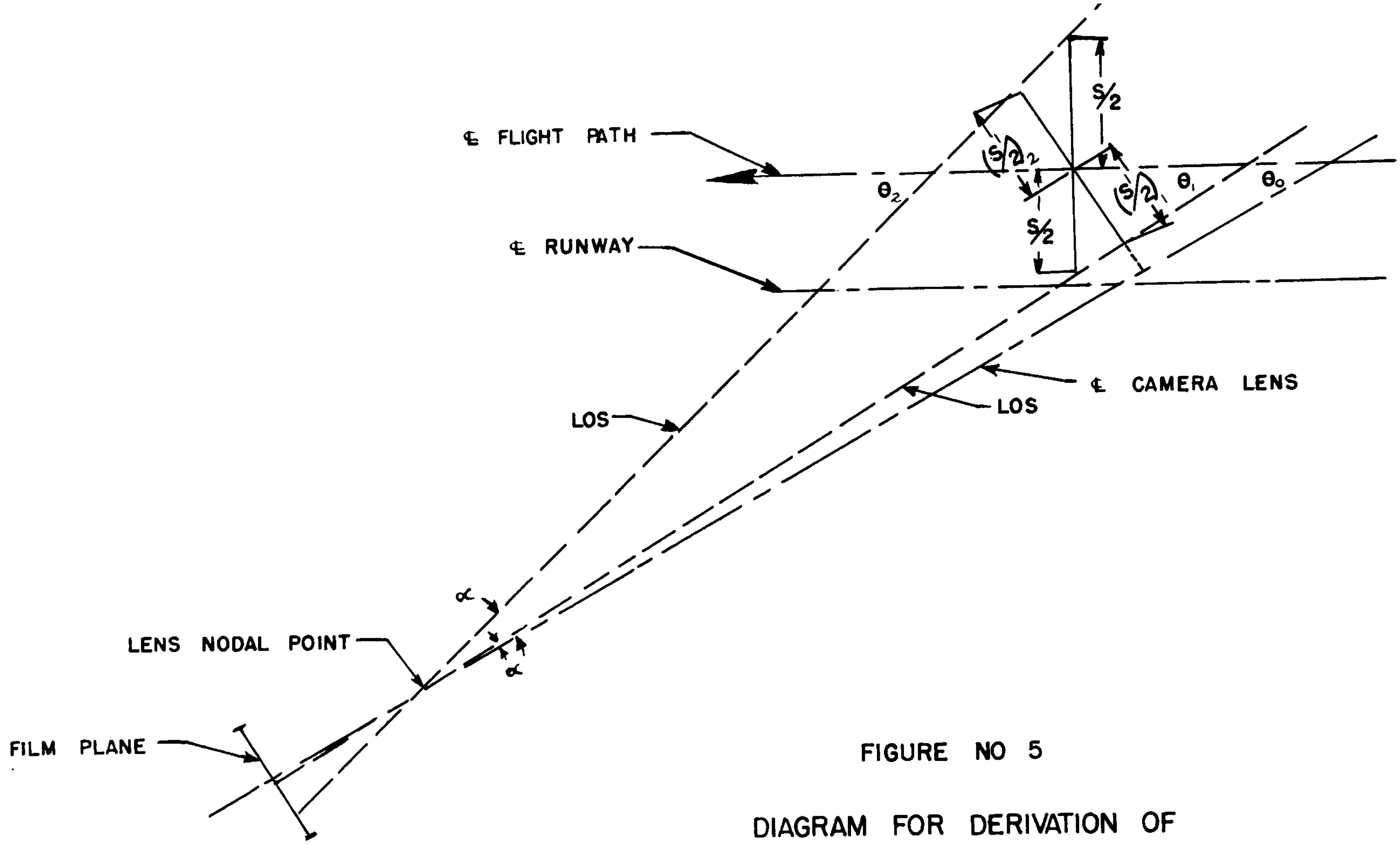


FIGURE NO 5

DIAGRAM FOR DERIVATION OF FORSHORTENED SPAN

EXAMPLE: FIND COSINE FUNCTION FOR

$$d = \frac{X_1 + X_2}{2W} = .65$$

1. LOCATE d = .65 ON CHART
2. DRAW A LINE FROM THIS POINT THROUGH POINT A TO OPPOSITE SIDE OF NOMOGRAPH
3. READ VALUE OF COSINE FUNCTION = 1.92

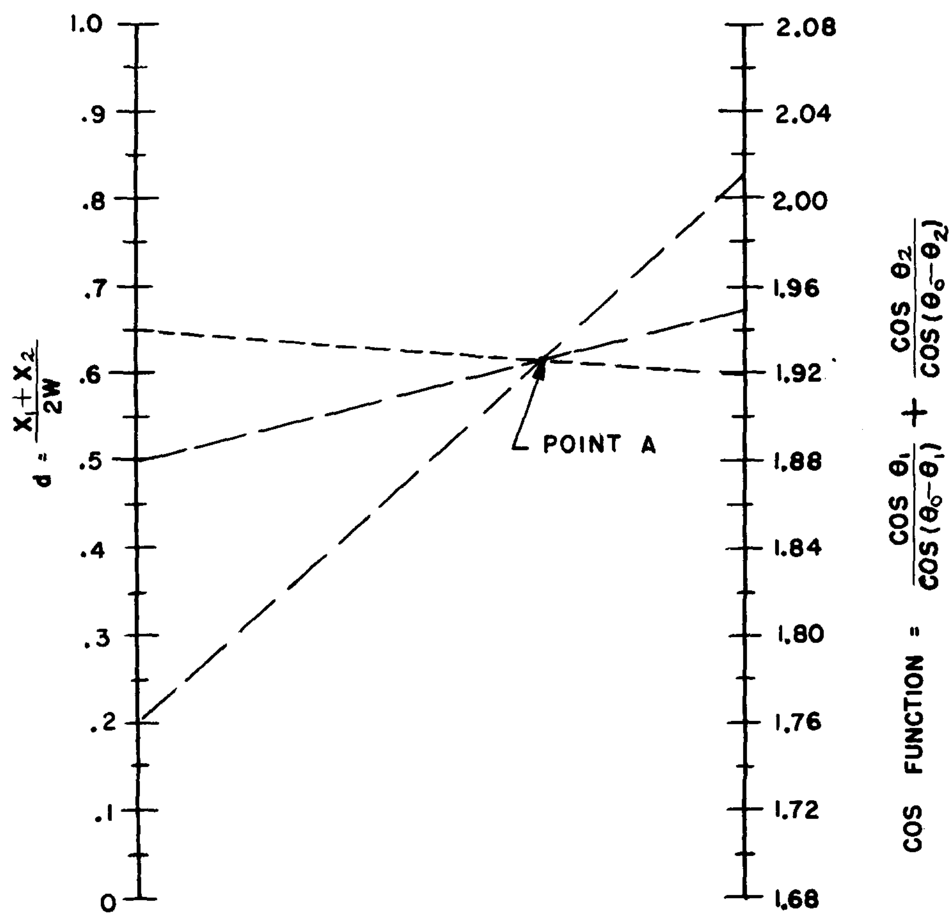
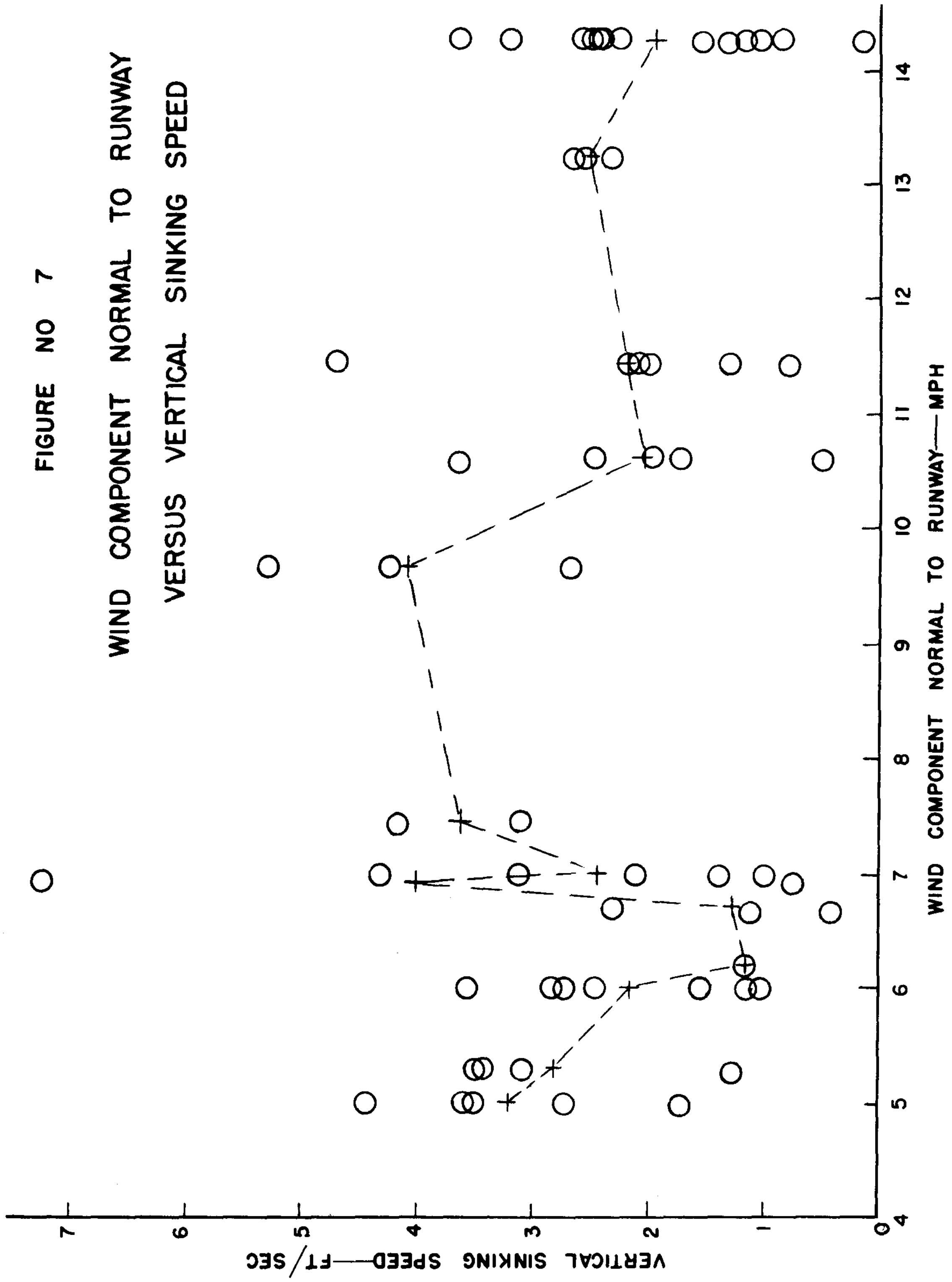


FIGURE NO 6

NOMOGRAPHIC CHART FOR DETERMINING THE COSINE FUNCTION

FIGURE NO 7

WIND COMPONENT NORMAL TO RUNWAY VERSUS VERTICAL SINKING SPEED



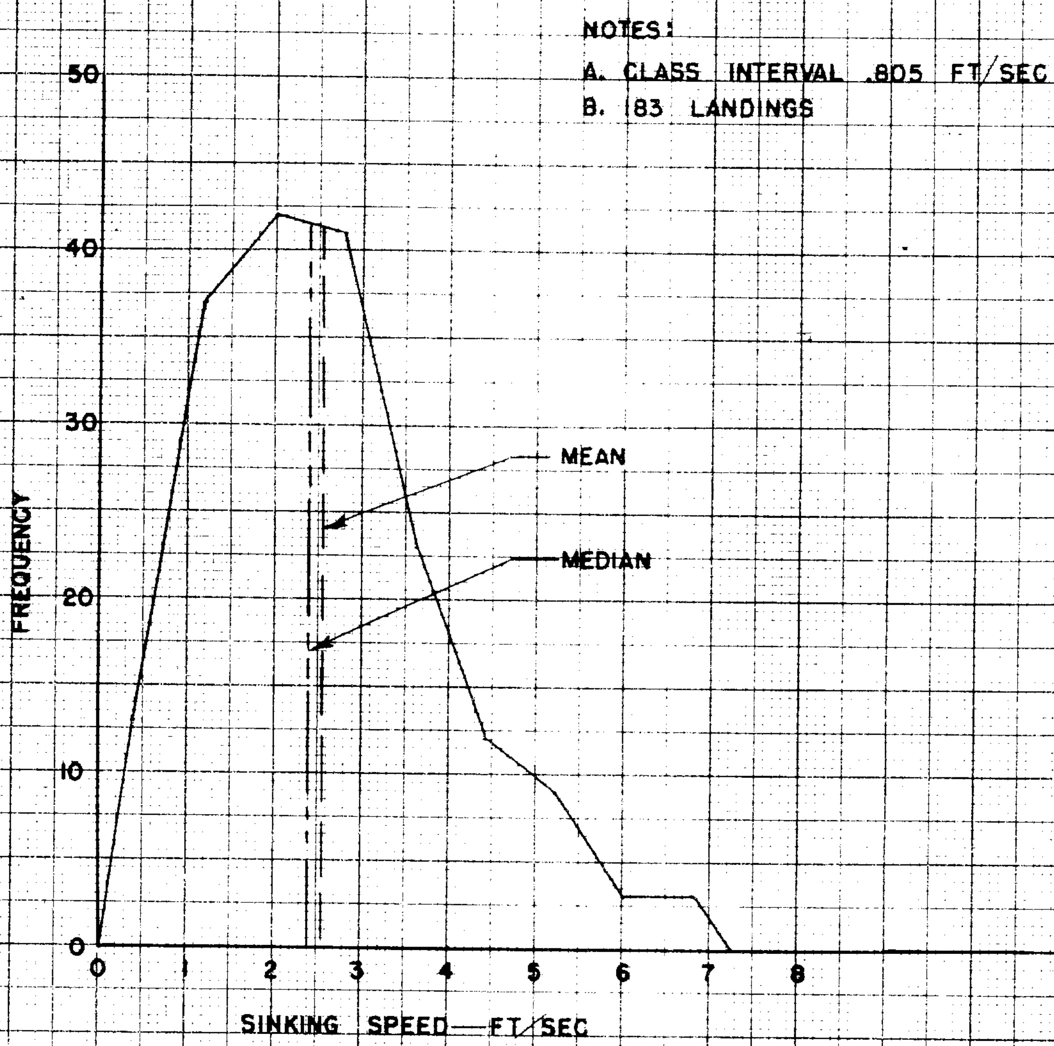


FIGURE NO 8

FREQUENCY POLYGON OF SINKING SPEEDS

HEAVY WEIGHT CONDITION

(TEMPELHOF)

359T-11 KEUFFEL & ESSER CO.
10 X 10 to the 1/2 inch, 5th lines accented.
MADE IN U.S.A.

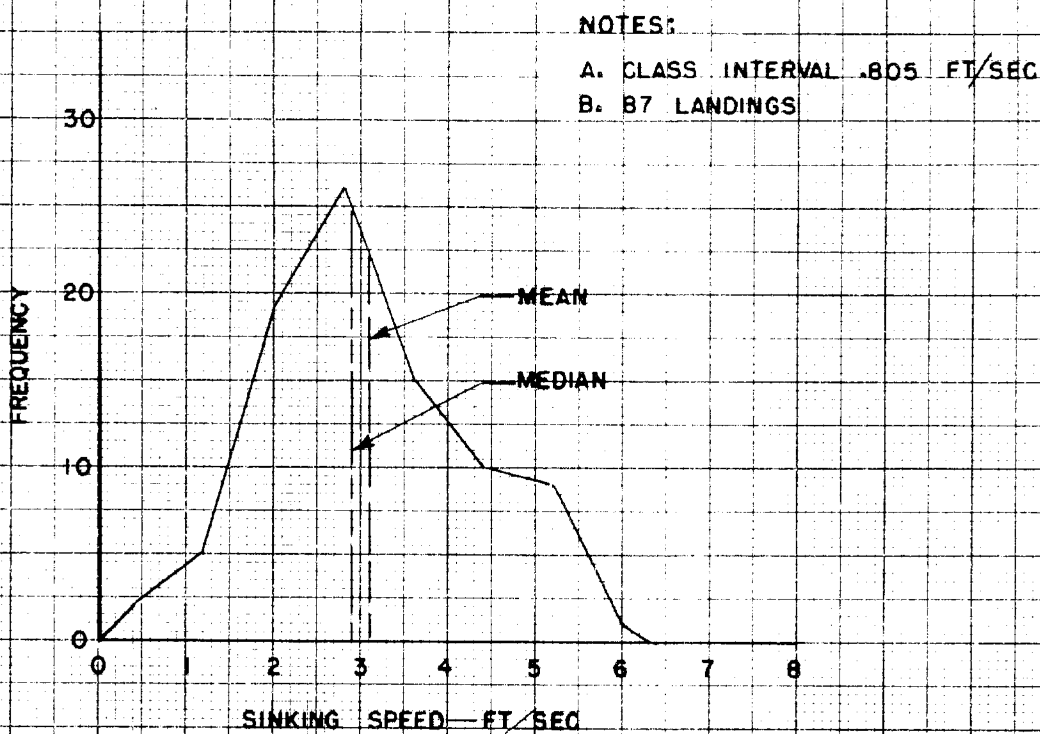


FIGURE NO 9

FREQUENCY POLYGON OF SINKING SPEEDS

LIGHT WEIGHT CONDITION

(RHEIN MAIN)

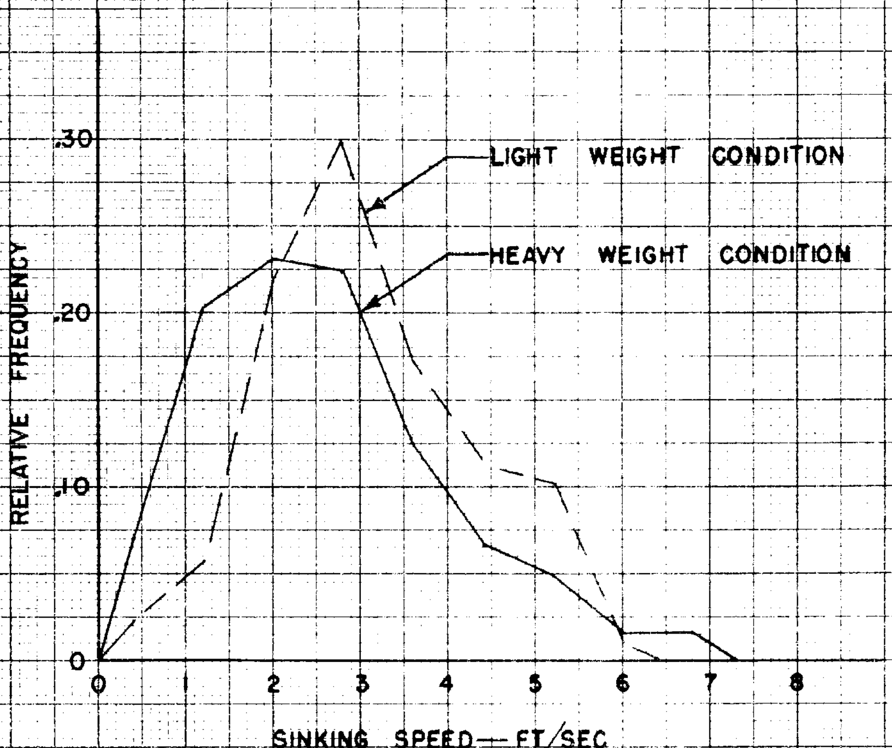


FIGURE NO 10

COMPARISON OF FREQUENCY POLYGONS OF
HEAVY WEIGHT AND LIGHT WEIGHT CONDITIONS

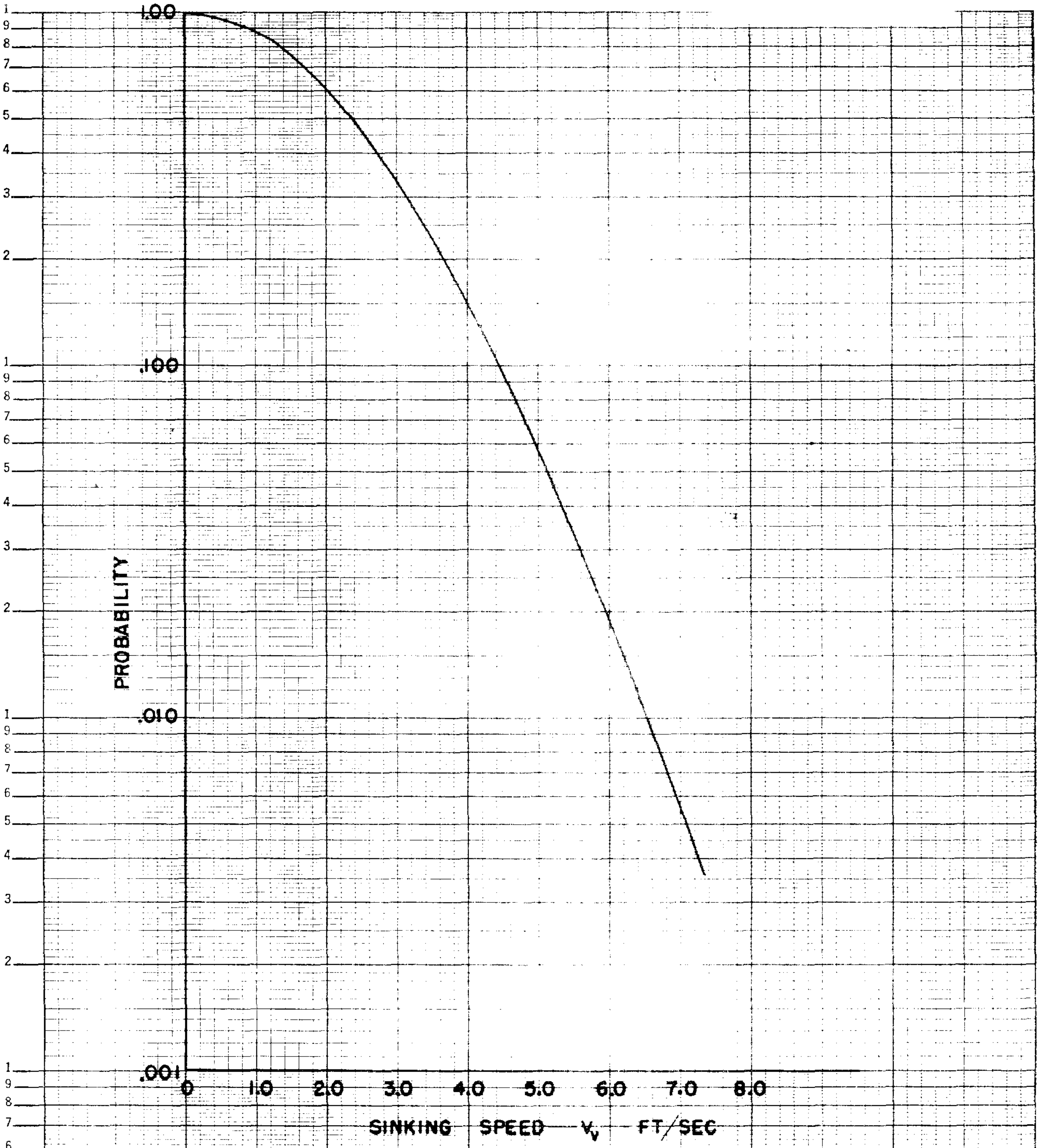


FIGURE NO 11

PROBABILITY OF EQUALING OR EXCEEDING SINKING SPEED

HEAVY WEIGHT CONDITION

(TEMPELHOF)

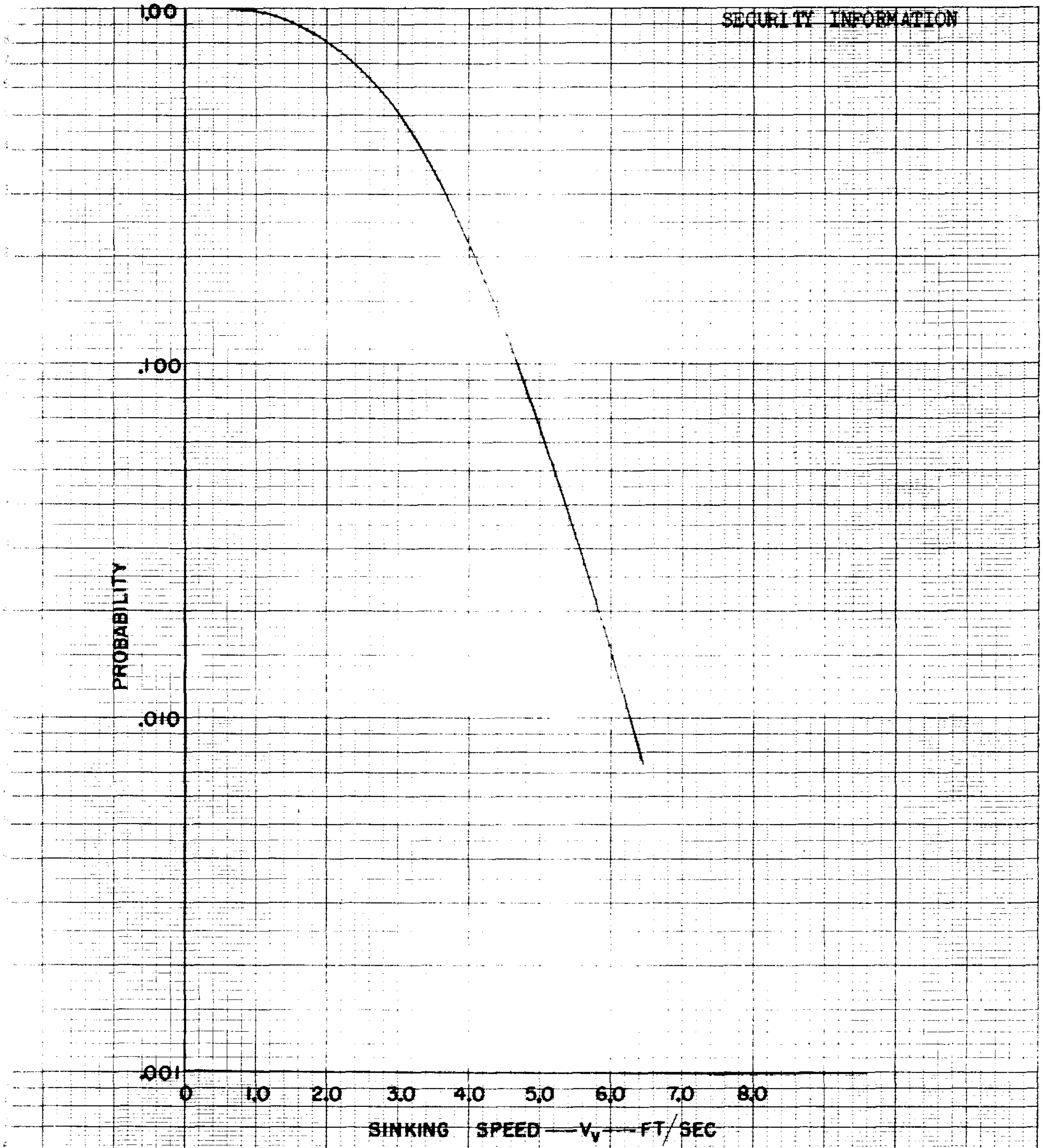


FIGURE NO 12

PROBABILITY OF EQUALING OR EXCEEDING SINKING SPEED

LIGHT WEIGHT CONDITION

(RHEIN MAIN)

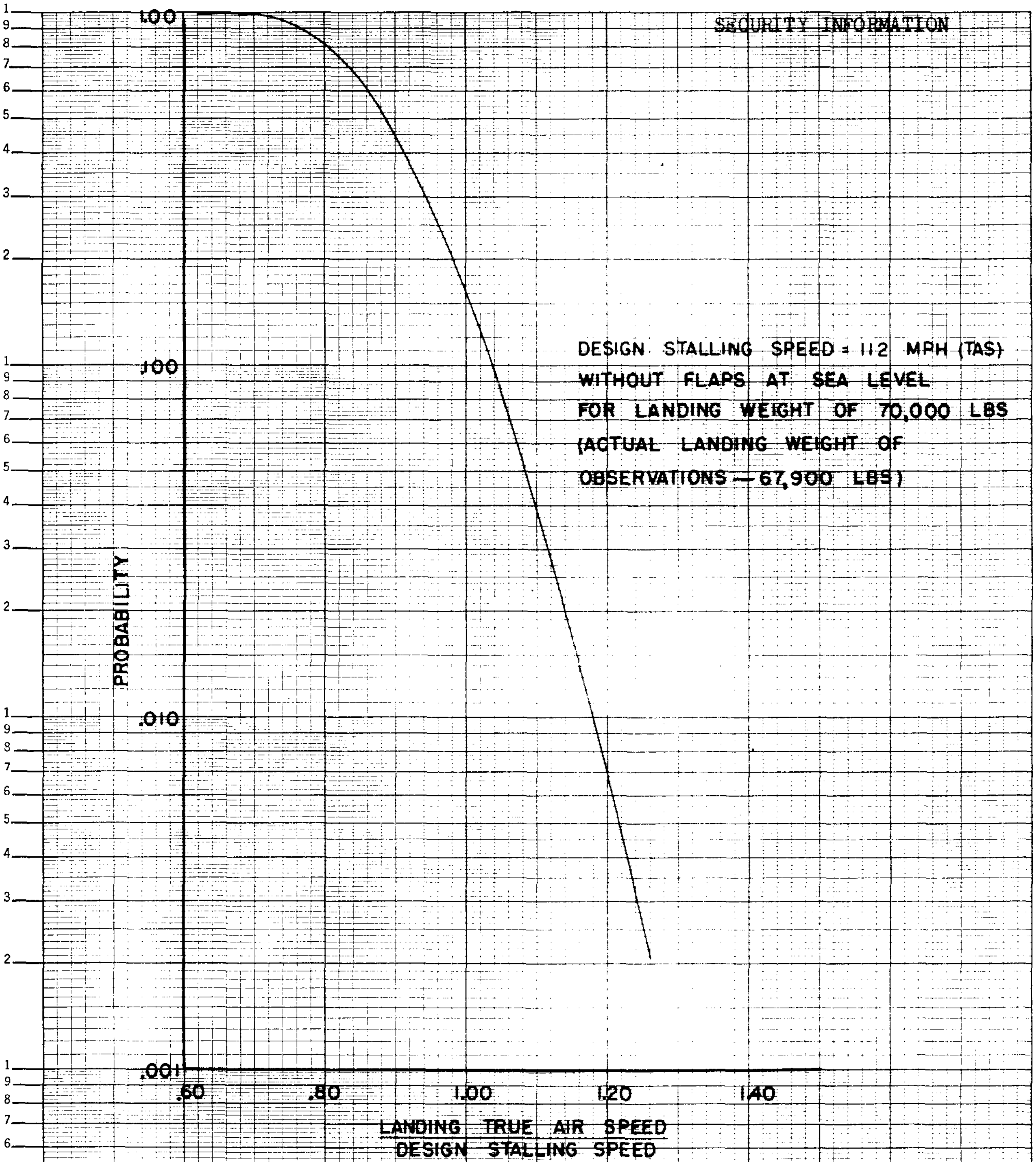


FIGURE NO 13

PROBABILITY OF EQUALING OR EXCEEDING LANDING SPEED

HEAVY WEIGHT CONDITION

(TEMPELHOF)

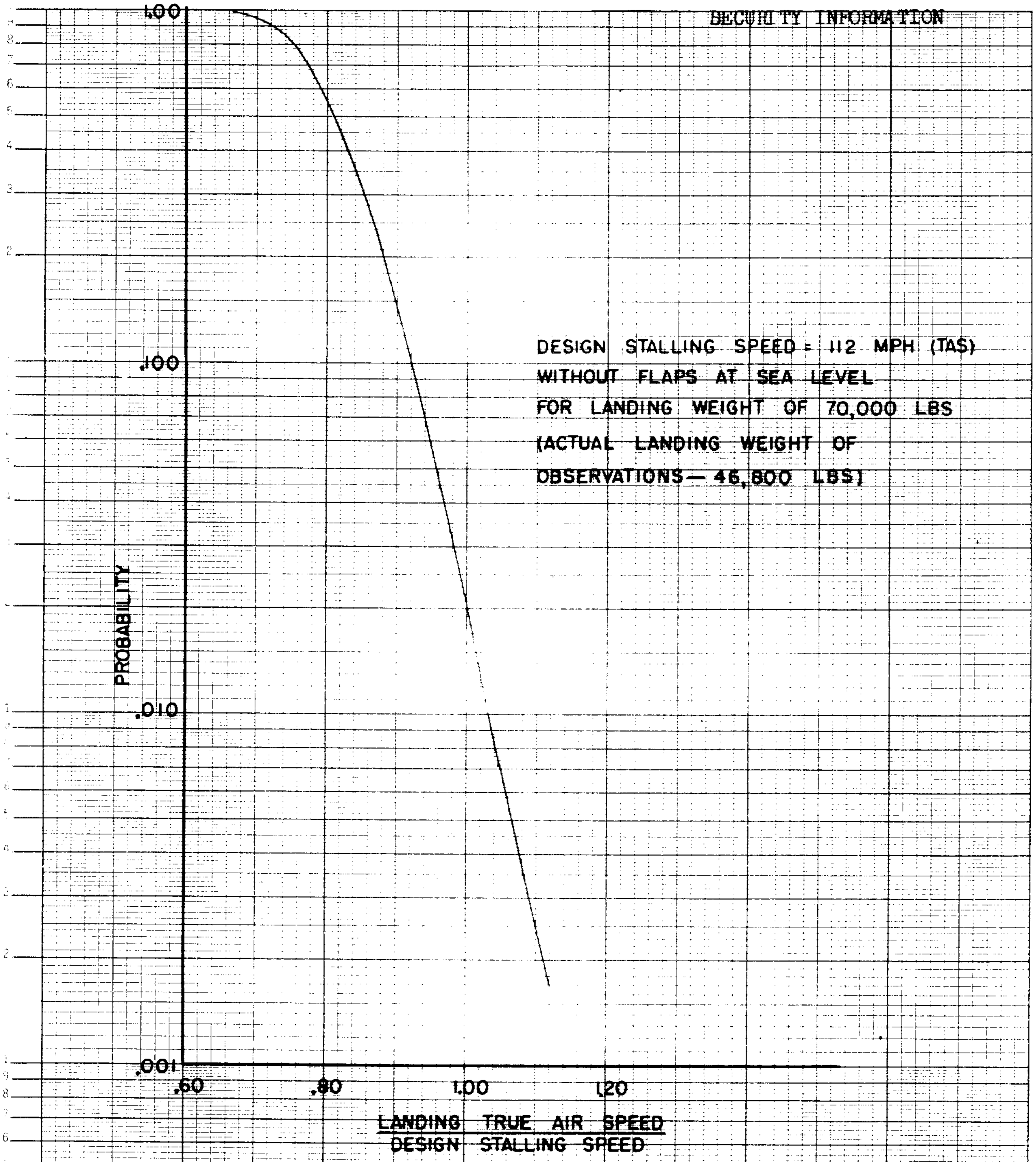


FIGURE NO 14

PROBABILITY OF EQUALING OR EXCEEDING LANDING SPEED

LIGHT WEIGHT CONDITION

(RHEIN MAIN)

FIGURE NO 15

WING LOAD FACTOR VS SINKING SPEED

HEAVY WEIGHT CONDITION

(TEMPELHOF)

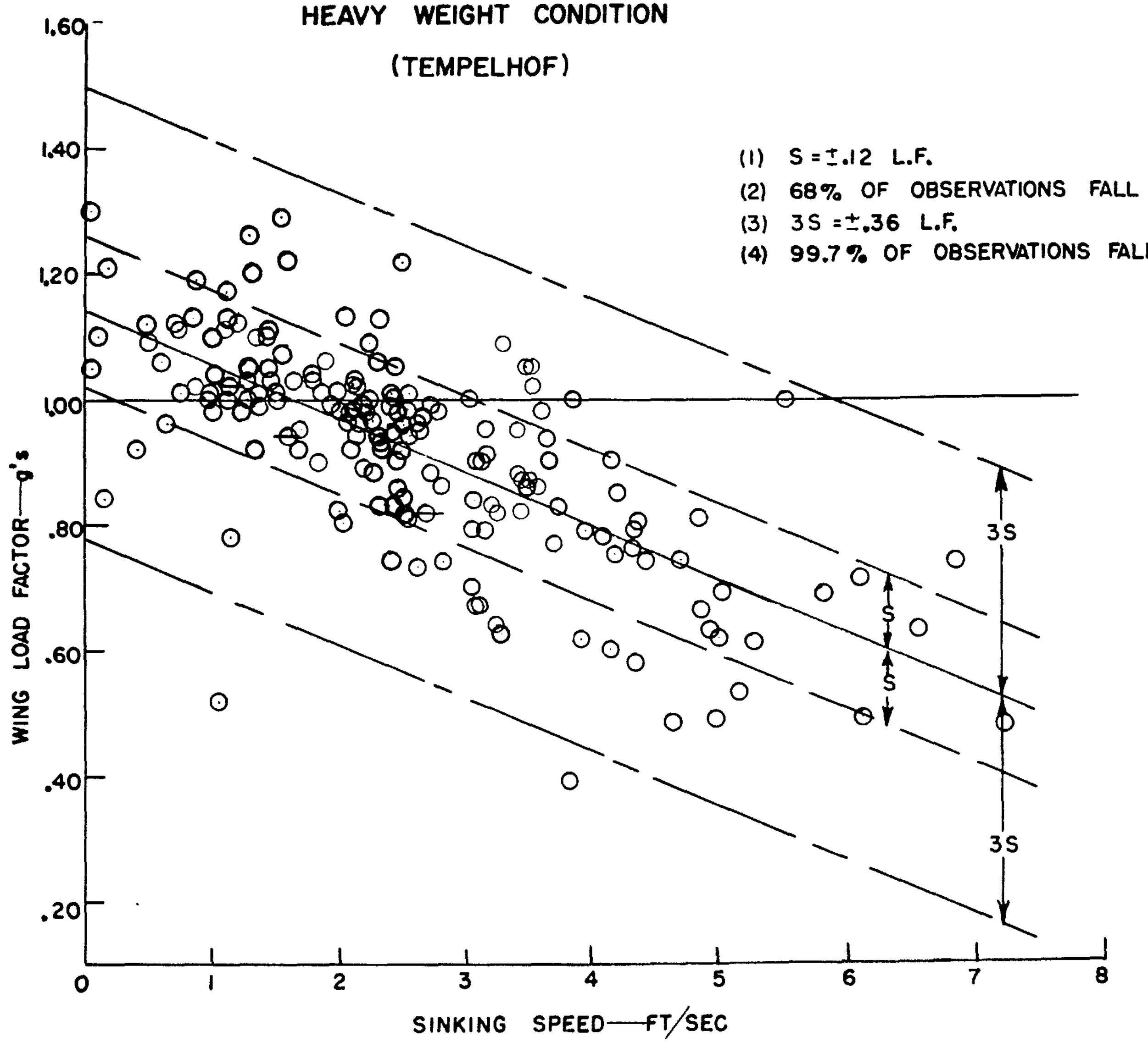
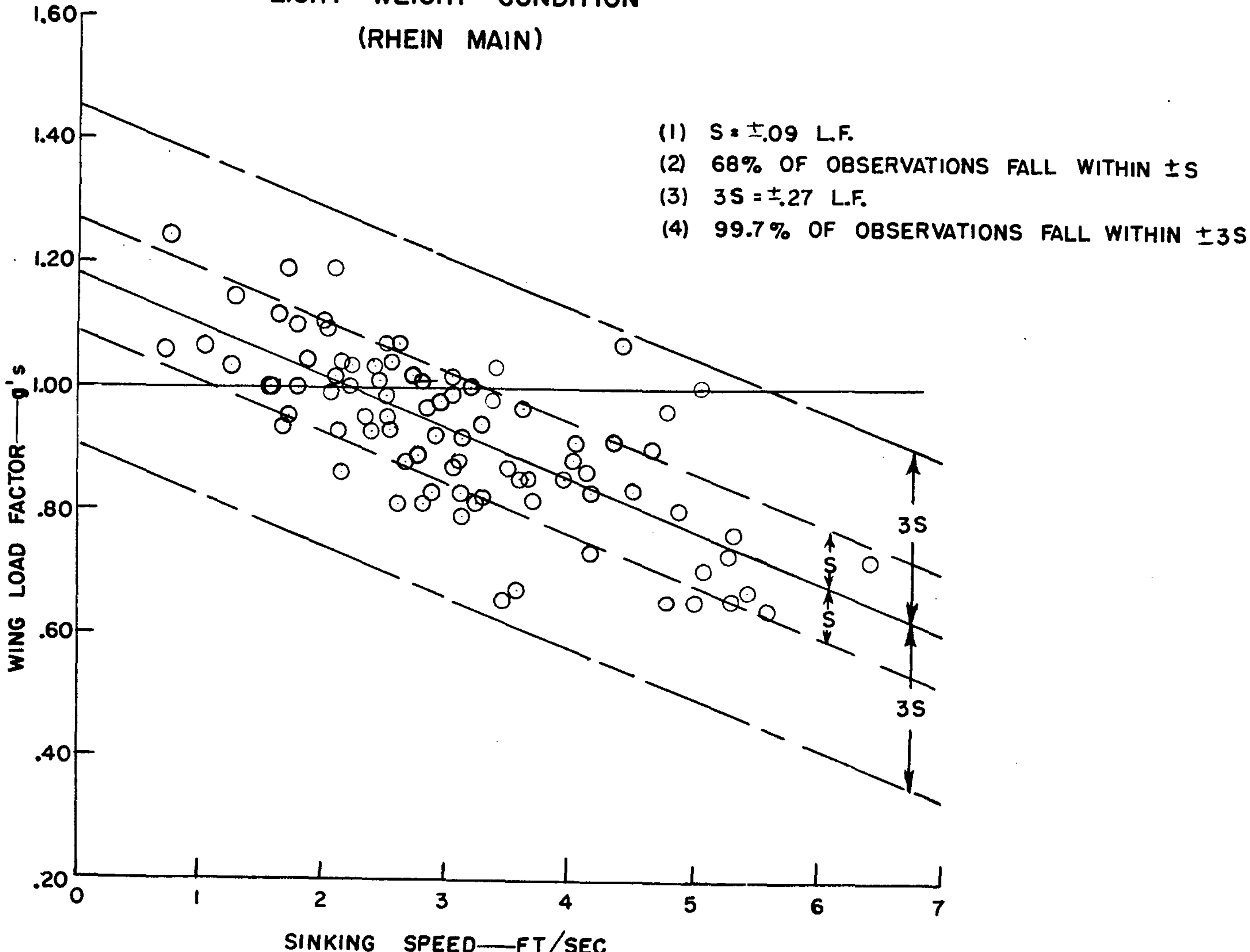


FIGURE NO 16

WING LOAD FACTOR VS SINKING SPEED

LIGHT WEIGHT CONDITION

(RHEIN MAIN)



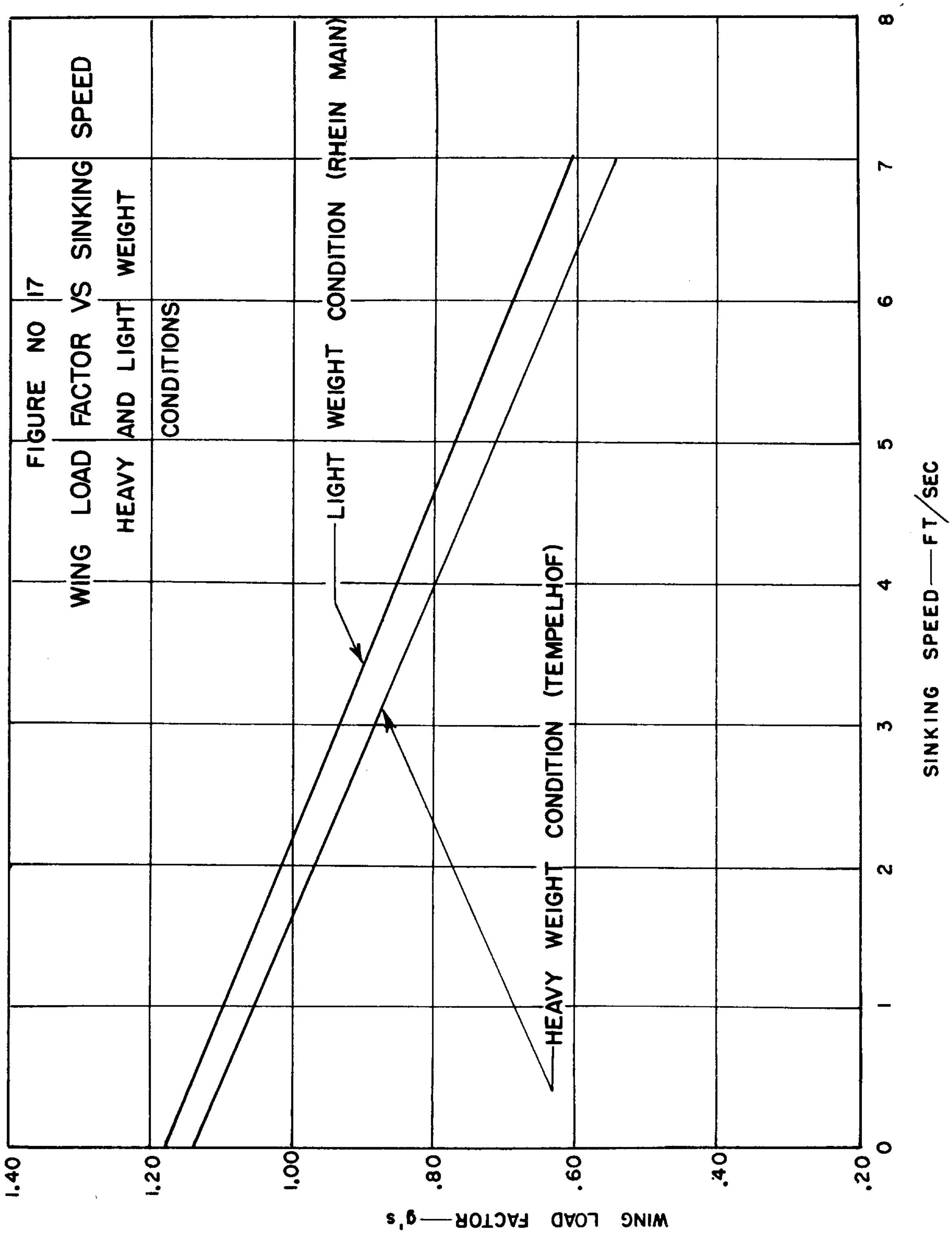


FIGURE NO 17
WING LOAD FACTOR VS SINKING SPEED
HEAVY AND LIGHT WEIGHT
CONDITIONS
LIGHT WEIGHT CONDITION (RHEIN MAIN)
HEAVY WEIGHT CONDITION (TEMPELHOF)
SINKING SPEED — FT/SEC
WING LOAD FACTOR — g's
0
1
2
3
4
5
6
7
8
1.40
1.20
1.00
.80
.60
.40
.20

APPENDIX I

Tables I and II in this Appendix present the results of the analysis of each individual landing, and the weather conditions prevailing during landing. Table III illustrates the calculations required to obtain sinking speed, acceleration, and horizontal speed during landing.

TABLE I
TEMPELHOF LANDINGS
(HEAVY WEIGHT COND.)

NUMBER	CLOCK NO.	SERIAL NO. OF AIRPLANE	DATE OF LANDING	TIME OF LANDING	RUNWAY HEADING	WIND DIRECTION	WIND VELOCITY (MPH)	VISIBILITY (MILES)	CEILING (FT)	TEMPERATURE (°F)	ANGLE OF ROLL-AT CONTACT	VERTICAL SINKING SPEED AT CONTACT (FT/SEC)	VERTICAL ACCELERATION AT CONTACT (g's)	FORWARD GROUNDSPEED AT CONTACT (MPH)	TRUE AIR SPEED AT CONTACT (MPH)
1	A-1	50854	22 Mar. 49	1453	267°44'	250°	8 MPH	10	UNL.	48° F		- 2.33	- .07	99.9	107.5
2	A-2		22 Mar. 49	1458	"	"	"	"	"	"	2°41'	- 3.71	- .23	96.8	104.0
3	A-4	272616	"	1505	"	"	"	"	"	"		- 2.42	+ .01	118.1	126.5
4	A-6	56540	"	1510	"	"	"	"	"	"		- 5.02	- .38	111.5	119.0
5	A-7	272480	"	1513	"	"	"	"	"	"		- 1.38	+ .11	102.3	110.0
6	A-8	272652	"	1515	"	"	"	"	"	"		- 3.10	- .10	89.8	97.0
7	A-11	272551	"	1529	"	"	3	"	"	"		- 2.53	- .16	101.5	104.5
8	A-12	272690	"	1533	"	"	"	"	"	"		+ .25	+ .30	113.0	115.0
9	A-13	272714	"	1541	"	"	"	"	"	"		- 1.21	+ .12	108.5	111.3
10	A-14	272600	"	1543	"	"	"	"	"	"		- 1.28	.00	129.3	132.0
11	A-15		"	1545	"	"	"	"	"	"		- 2.13	- .03	101.5	104.2
12	A-16	272523	"	1548	"	220°	5	"	"	"		- 4.87	- .34	110.9	114.4
13	A-17	317233	"	1551	"	"	"	"	"	"		- 2.17	- .04	104.3	108.0
14	A-19	5566	"	1556	"	"	"	"	"	"		- 3.41	- .12	99.3	102.9
15	A-20	5626	"	1559	"	"	"	"	"	"		- .60	+ .06	96.2	100.0
16	A-21	56510	"	1607	"	"	"	"	"	"		- 4.10	- .22	119.8	123.5
17	A-24	272726	"	1620	"	"	"	"	"	"		- 1.61	- .06	90.9	94.3
18	A-25	5544	"	1622	"	"	"	"	"	"		- 3.46	- .13	90.5	94.0
19	A-26	87757	"	1625	"	"	"	"	"	"		- 1.65	+ .03	101.3	105.0
20	A-28	56505	"	1642	"	"	"	"	"	"		- 2.08	- .04	93.0	97.2
21	A-30	317227	"	1648	"	230°	4	"	"	"		- 1.47	+ .03	96.3	99.0
22	A-32	2-72440	"	1653	"	"	"	"	"	"		- 1.61	- .06	87.5	90.1
23	A-33	5510	"	1705	"	"	"	10	"	48° F		-	-	108.6	111.2
24	A-35	49126	23 Mar. 49	1107	267°44	360°	6	2 3/4	UNL.	45° F		- 1.03	+ .04	+107.5	107.0
25	A-36	4-9048	"	1115	"	"	"	"	"	"		-3.55	+ .02	97.2	96.9
26	A-39	272505	"	1126	"	"	"	3	"	46°F		-2.72	-.12	106.8	106.5
27	A-40	50859	"	1130	"	"	"	"	"	"		-2.80	-.02	102.1	101.9
28	A-41	50852	"	1132	"	"	"	"	"	"		-2.44	.00	105.3	105.0
29	A-42	2-72617	"	1135	"	"	"	"	"	"		-1.53	.00	97.3	97.0
30	A-43	5-491	"	1139	"	"	"	"	"	"		-1.14	+ .02	97.2	96.9
31	A-45	272459	"	1153	"	"	3	"	"	47°F		-3.16	-.05	95.9	95.7
32	A-46	50854	"	1159	"	"	"	"	"	"		-1.00	+.01	101.5	101.4
33	A-48	56544	"	1212	"	"	"	"	"	"		-3.17	-.09	93.6	93.5
34	A-49	5-482	"	1217	"	"	7	"	"	48°F		-2.09	-.02	94.3	94.0
35	A-51		"	1228	"	"	"	"	"	"		-1.38	-.01	91.8	91.5
36	A-53	2-72551	"	1233	"	"	"	"	"	"		-4.32	-.24	97.4	97.0
37	A-57	272537	"	1244	"	"	"	"	"	"		-3.12	-.10	100.4	100.0
38	A-58	90912	"	1245	"	"	"	"	"	"		-0.99	.00	92.4	92.0
39	A-62	50855	"	1303	"	"	5	4	"	"		-4.45	-.26	103.7	103.4
40	A-63	5566	"	1307	"	"	"	"	"	"		-1.45	+ .05	101.2	100.9
41	A-64	49096	"	1320	"	320°	4	5	"	"		-3.87	.00	104.8	106.0
42	A-66	2-72720	"	1326	"	"	"	"	"	"		-6.11	-.29	93.2	95.3
43	A-67	50858	"	1329	"	"	"	"	"	"		-5.81	-.31	100.0	103.0
44	A-68	2-72579	"	1336	"	"	"	"	"	"		-1.02	+ .10	119.1	121.2
45	A-69	5-503	"	1342	"	"	"	"	"	"		-2.24	.00	126.0	128.3
46	A-74	50851	"	1417	"	360°	5	6	"	49°F		-3.51	+ .05	112.3	108.1
47	A-78	2-72440	"	1429	"	"	"	"	"	"		-2.71	-.18	119.0	118.2
48	A-80	49130	23 Mar 49	1437	267°44'	360°	5	6	UNL	49°F		-3.61	-.02	101.2	100.8
49	A-81	50864	"	1440		"	"	"	"	"		-1.70	-.08	91.2	91.0
50	A-82	49066	"	1448	"	"	3	7	"	51°F		-1.36	+ .10	92.3	92.1
51	A-83	2-72566	"	1451	"	"	"	"	"	"		-2.64	-.04	101.0	100.8
52	A-84	2-72658	"	1455	"	"	"	"	"	"		-1.11	+ .17	106.5	106.3
53	A-85	272663	"	1459	"	"	"	"	"	"		-2.50	+ .22	104.8	104.6
54	A-87	3-17245	"	1509	"	"	"	"	"	"		-2.23	- .02	94.0	93.8
55	A-89	2-72547	"	1518	"	"	2	10	"	"		-0.48	+ .12	109.2	109.2

TABLE I (Cont.)
TEMPELHOF LANDINGS
(HEAVY WEIGHT COND.)

NUMBER	CLOCK NO.	SERIAL NO. OF AIRPLANE	DATE OF LANDING	TIME OF LANDING	RUNWAY HEADING	WIND DIRECTION	WIND VELOCITY (MPH)	VISIBILITY (MILES)	CEILING (FT)	TEMPERATURE (°F)	ANGLE OF ROLL AT CONTACT	VERTICAL SINKING SPEED AT CONTACT (FT/SEC)	VERTICAL ACCELERATION AT CONTACT (g's)	FORWARD GROUNDSPEED AT CONTACT (MPH)	TRUE AIR SPEED AT CONTACT (MPH)
56	A-90	50868	"	1520	"	"	"	"	"	"		-1.37	+ .01	111.8	111.7
57	A-93	5-515	"	1532	"	"	"	"	"	"		-3.30	+ .09	105.2	105.1
58	A-95	4-9032	"	1543	"	"	"	"	"	"		-2.07	+ .13	108.7	108.7
59	A-98	272511	"	1554	"	"	1	"	"	"		-1.44	+ .10	87.9	87.9
60	B-1	272619	"	1606	"	"	"	"	"	"		-0.87	+ .02	100.5	100.5
61	B-2	272726	"	1615	"	"	"	"	"	"		-0.88	+ .19	99.8	99.8
62	B-4	56510	"	1619	"	"	3	"	"	"		-2.12	-.02	96.0	95.9
63	B-6	50859	23 Mar 49	1641	"	"	"	"	"	"		-6.55	-.37	102.1	101.9
64	B-8	272553	24 Mar 49	1028	"	90°	"	5	"	48° F		-1.87	+ .01	107.9	104.9
65	B-9	272511	"	1031	"	"	"	"	"	"		-1.45	+ .11	130.6	128.1
66	B-10	272600	"	1036	"	"	"	"	"	"		-4.15	-.40	112.9	110.2
67	B-11	5495	"	1039	"	"	"	"	"	"		-1.02	-.02	102.7	100.0
68	B-12	87757	"	1041	"	"	"	"	"	"		-1.90	+ .06	100.6	97.6
69	B-13	5510	"	1044	"	"	"	"	"	"		-3.16	-.21	108.2	105.5
70	B-14	5548	"	1048	"	"	"	"	"	"		-2.40	-.26	112.2	109.6
71	B-16	272505	"	1102	"	"	"	"	"	"		-4.86	-.19	110.3	107.6
72	B-17	56544	24 Mar 49	1105	267°44'	360°	3	5	UNL	48°F		-3.49	+ .05	93.5	91.2
73	B-18	56522	"	1111	"	90°	"	"	"	"		-2.14	- .06	115.8	112.9
74	B-19	49134	"	1115	"	"	"	"	"	"		-2.45	- .10	101.0	98.1
75	B-21	49130	"	1320	87°44'	"	8	10	"	54°F		-2.82	- .14	105.5	113.0
76	B-26	5491	"	1347	"	"	10	"	"	"		-2.02	- .18	89.6	99.6
77	B-37	49032	"	1454	"	"	"	"	"	"		-3.02	.00	97.5	107.5
78	B-38	272654	"	1456	"	"	"	"	"	"		-1.80	+ .03	89.5	98.8
79	B-39	262495	"	1512	"	"	"	"	"	"		-1.16	- .22	95.0	105.2
80	B-46	2725553	"	1559	"	"	8	"	"	55°F		-4.98	- .51	103.2	113.2
81	B-48	5510	"	1605	"	"	"	"	"	"		-2.11	- .08	105.8	115.8
82	B-49	5548	24 Mar. 49	1608	87°44'	90°	8	10	"	55°F		-3.11	- .33	100.6	92.0
83	B-53	272537	25 Mar. 49	0919	267°44'	-	DATA	NOT	AVAILABLE			- .70	+ .12	99.2	-
84	B-54	272616	"	0923	"	"	"	"	"	"		-2.59	+ .01	93.3	-
85	B-55	56507	"	0929	"	"	"	"	"	"		-3.50	- .13	93.3	-
86	B-57	5566	"	0935	"	"	"	"	"	"		-2.21	- .01	91.7	-
87	B-61	5582	"	1007	"	"	"	"	"	"		-2.42	- .17	91.2	-
88	B-62	5584	"	1010	"	"	"	"	"	"		-1.36	- .08	98.1	-
89	B-68	90393	"	1037	"	"	"	"	"	"		-1.53	+ .01	111.0	-
90	B-71	90912	"	1046	"	150°	10	10	UNL	54°F		- .16	- .16	91.3	87.3
91	B-76	317199	"	1100	"	"	"	"	"	"		-3.07	- .21	85.3	81.6
92	B-77	50868	"	1103	"	"	"	"	"	"		-0.64	- .04	112.1	108.0
93	B-78	272480	"	1107	"	"	"	"	"	"		-3.24	- .36	103.8	99.8
94	B-79	272566	25 Mar. 49	1109	267°44'	150°	10	10	UNL	54°F		-1.80	+ .04	99.5	95.2
95	B-80	56528	"	1113	"	"	"	"	"	"		-4.17	- .10	82.5	78.0
96	B-82	272523	"	1119	"	160°	12	"	"	55°F		- .76	+ .01	103.1	100.6
97	B-83	272615	25 Mar. 49	1121	267°44'	160°	12	10	UNL	55°F		-2.14	+ .02	89.8	87.5
98	B-85	49134	"	1127	"	"	"	"	"	"		-1.29	+ .05	92.8	90.5
99	B-87	56543	"	1136	"	"	"	"	"	"		-2.00	+ .01	96.1	93.5
100	B-88	272477	"	1138	"	"	"	"	"	"		-2.12	+ .02	88.6	86.3
101	B-89	272603	"	1142	"	"	"	"	"	"		-4.71	- .26	92.6	90.3
102	B-91	272608	"	1149	"	150°	10	"	"	59°F		-2.73	- .01	91.3	88.0
103	B-92	272708	"	1152	"	"	"	"	"	"		-5.53	+ .00	~~106.5~~	102.5
104	B-96	50873	"	1214	"	"	"	"	"	"		-1.33	+ .20	92.9	88.5
105	B-97	5542	"	1219	"	"	12	"	"	"		-2.44	+ .05	94.0	88.8
106	B-98	49131	"	1224	"	"	"	"	"	"		-1.96	- .01	95.4	90.5
107	B-99	5495	"	1227	"	"	"	"	"	"		-0.50	+ .09	115.8	111.0
108	C-0	272511	"	1229	"	"	"	"	"	"		-1.71	- .05	112.3	107.5
109	C-1	5544	"	1233	"	"	"	"	"	"	2°31'	-3.64 -3.11	- .06 + .13	106.2	101.8
110	C-3	5510	"	1252	"	"	15	"	"	61°F		- 2.31	- .06	146.9	140.0

TABLE I (Cont.)
TEMPELHOF LANDINGS
(HEAVY WEIGHT COND.)

NUMBER	CLOCK NO.	SERIAL NO. OF AIRPLANE	DATE OF LANDING	TIME OF LANDING	RUNWAY HEADING	WIND DIRECTION	WIND VELOCITY (MPH)	VISIBILITY (MILES)	CEILING (FT)	TEMPERATURE (°F)	ANGLE OF ROLL AT CONTACT	VERTICAL SINKING SPEED AT CONTACT (FT/SEC)	VERTICAL ACCELERATION AT CONTACT (g's)	FORWARD GROUNDSPEED AT CONTACT (MPH)	TRUE AIR SPEED AT CONTACT (MPH)
111	C-4	5614	"	1304	"	"	"	"	"	"		-2.67	- .03	126.1	119.8
112	C-8	5500	"	1327	"	160°	"	"	"	"		-2.58	- .07	116.7	113.0
113	C-11	272555	"	1343	"	"	"	"	"	"		-1.13	+ .13	105.2	102.0
114	C-12	272609	"	1345	"	"	"	"	"	"		-2.51	- .04	103.1	99.5
115	C-13	50866	"	1347	"	"	"	"	"	"		-1.56	+ .29	137.1	133.5
116	C-24	50864	"	1452	"	"	"	"	"	64°F		-0.18	+ .21	99.3	96.0
117	C-28	5582	"	1522	"	"	"	"	"	"		-3.21	- .17	105.0	101.5
118	C-30	49119	"	1527	"	"	"	"	"	"		-2.40	- .01	109.2	105.5
119	C-31	272575	"	1530	"	"	"	"	"	"		-3.64	-.10	108.6	105.0
120	C-32	272486	"	1536	267°44'	160°	15	10	UNL	64°F		- .86	+ .13	87.3	84.0
121	C-33	90393	25 Mar. 49	1539	267°44'	160°	15	10	UNL	64°F		-2.55	- .19	91.4	88.0
122	C-34	317227	"	1543	"	"	"	"	"	"	3°02'	-1.30 -1.21	+ .26 + .02	93.0	89.5
123	C-39	272663	"	1605	"	"	"	"	"	68°F		-2.46	- .14	95.7	92.3
124	C-40	5584	"	1608	"	"	"	"	"	"		-2.25	+ .09	107.0	103.0
125	C-42	317228	"	1615	"	"	"	"	"	"		-1.06	- .48	97.5	94.3
126	C-43	272553	"	1622	"	"	"	"	"	64°F	3°12'	-	-	94.6	91.0
127	C-44	272505	"	1625	"	"	"	"	"	"		-	-	109.0	105.6
128	C-46	50873	26 Mar. 49	1020	"	270°	3	2 Haze	"	54°F		-4.64	- .52	90.4	93.2
129	C-47	317199	"	1024	"	"	"	"	"	"		-5.02	- .31	112.2	114.8
130	C-51	5584	"	1038	"	"	"	"	"	"		- .06	+ .05	93.4	96.2
131	C-52	5491	"	1045	"	"	"	"	"	"		-1.24	- .02	94.6	97.0
132	C-53	49126	"	1049	"	"	5	3 Haze	"	55°F		-4.34	- .21	99.0	101.6
133	C-56	272526	"	1103	"	"	"	"	"	"		-3.29	- .37	95.5	105.5
134	C-57	272562	"	1105	"	"	"	"	"	"		-2.34	- .08	93.9	98.9
135	C-58	5500	"	1136	"	260°	6	4 Haze	"	60°F		-2.04	- .20	99.7	100.5
136	C-59	90436	"	1139	"	"	"	"	"	"		-2.13	+ .03	111.8	112.5
137	C-60	272720	"	1144	"	"	"	"	"	"		-0.11	+ .10	98.7	99.5
138	C-62	272722	"	1157	"	310°	10	5 Haze	"	"		-0.42	- .08	102.0	109.8
139	C-63	272663	"	1159	"	"	"	"	"	"		-2.29	- .12	90.4	93.0
140	C-64	317245	"	1202	"	"	"	"	"	"		-1.13	.00	94.0	102.0
141	C-68	5548	"	1219	"	270°	4	6	"	61°F		-0.05	+ .30	115.2	118.6
142	C-69	90393	"	1226	"	"	"	"	"	"		-3.90	- .38	77.3	80.5
143	C-73	272608	"	1239	"	"	"	"	"	"		-2.62	- .27	115.1	118.5
144	C-75	272444	"	1301	"	320°	7	6	UNL	63°F		- .73	+ .11	119.9	123.5
145	C-77	50855	26 Mar. 49	1313	267°44'	320°	7	6	UNL	63°F		-7.23	- .52	82.6	86.0
146	C-80	272726	"	1325	"	290°	"	"	"	"		-2.32	- .17	83.8	90.0
147	C-83	272550	"	1341	"	"	"	"	"	"		-2.53	- .18	96.6	102.7
148	C-90	90421	"	1420	"	300°	10	"	"	64°F		-3.43	- .18	91.4	100.0
149	C-92	5614	"	1432	"	"	"	"	"	"		-3.09	- .33	105.3	114.0
150	C-94	56528	"	1438	"	"	"	"	"	"		-3.49	- .14	103.7	112.6
151	C-95	317223	"	1443	"	"	"	"	"	"		-1.28	+ .03	97.4	104.9
152	C-97	5542	"	1450	"	330°	7	"	"	"		-5.16	- .47	87.5	90.0
153	D-0	50854	"	1511	"	"	"	"	"	"		-1.15	+ .02	95.9	98.8
154	D-2	272440	"	1521	"	310°	5	"	"	"		-3.83	- .61	96.2	99.5
155	D-4	50873	"	1529	"	"	"	"	"	"		-3.25	- .18	104.3	107.5
156	D-5	5602	"	1532	"	"	"	"	"	"		-3.05	- .30	90.4	93.8
157	D-6	272495	"	1543	"	"	"	"	"	"		-2.27	- .03	96.6	99.8
158	D-7	272505	"	1544	"	"	"	"	"	"		-4.36	- .42	115.5	118.8
159	D-8	5491	"	1549	"	280°	7	"	"	"		-4.94	- .37	110.5	117.5
160	D-14	90912	27 Mar 49	1059	"	80°	8	3	"	54°F		-1.85	- .10	115.6	108.0
161	D-15	272726	"	1100	"	"	"	"	"	"		-2.30	+ .06	110.5	102.9
162	D-16	5612	"	1109	"	"	"	"	"	"		-1.62	+ .22	115.5	107.9
163	D-19	272566	"	1157	"	"	"	6	"	57°F		-3.60	- .14	91.3	83.8
164	D-20	5488	"	1200	267°44'	80°	"	"	"	"		-2.19	- .11	97.7	90.0
165	D-22	2663	"	1208	167°44'	"	"	"	"	"		-2.58	- .02	102.5	94.6

TABLE I (Cont.)
TEMPELHOF LANDINGS
(HEAVY WEIGHT COND.)

NUMBER	CLOCK NO.	SERIAL NO. OF AIRPLANE	DATE OF LANDING	TIME OF LANDING	RUNWAY HEADING	WIND DIRECTION	WIND VELOCITY (MPH)	VISIBILITY (MILES)	CEILING (FT)	TEMPERATURE (°F)	ANGLE OF ROLL AT CONTACT	VERTICAL SINKING SPEED AT CONTACT (FT/SEC)	VERTICAL ACCELERATION AT CONTACT (g's)	FORWARD GROUNDSPEED AT CONTACT (MPH)	TRUE AIR SPEED AT CONTACT (MPH)
166	D-25	5495	"	1229	"	"	10	"	"	59°F		-2.02	- .02	96.4	87.4
167	D-29	272743	"	1307	"	"	8	"	"	"		-3.41	- .05	83.4	73.5
168	D-31	56540	"	1315	"	"	"	"	"	"		-2.50	- .08	95.7	87.5
169	D-32	272579	27 Mar 49	1317	167°44'	80°	7	6	UNL	59°F		-4.36	- .20	120.9	113.0
170	D-34	272459	"	1325	"	"	"	"	"	"		-3.75	- .17	94.6	86.8
171	D-35	272575	"	1329	"	"	"	"	"	"		-2.45	- .02	95.2	87.5
172	D-36	56493	"	1331	"	"	"	"	"	"		-3.95	- .21	107.5	100.0
173	D-40	272495	"	1351	"	"	9	"	"	"	2°31'	-1.57 + .19	+ .07 + .21	109.5	102.0
174	D-43	56505	"	1404	"	"	"	"	"	"		-6.82	- .26	104.9	95.7
175	D-45	272440	"	1412	"	"	"	"	"	"		-2.83	- .26	102.1	93.6
176	D-46	90421	"	1415	"	"	"	"	"	"		-1.56	+ .06	90.4	81.4
177	D-47	49134	"	1419	"	40°	5	7	"	"		-2.69	- .18	95.8	92.8
178	D-49	272480	"	1426	"	"	"	"	"	"	3°32'	-2.59 -1.43	- .06 + .08	97.8	94.0
179	D-54	49131	"	1454	"	"	13	10	"	57°F		-2.66	-.05	100.5	92.0
180	D-56	5482	"	1503	"	"	"	"	"	"		-5.27	- .39	97.4	88.9
181	D-57	272690	"	1505	"	"	"	"	"	"		-4.23	- .15	76.8	69.7
182	D-63	50859	"	1526	"	"	10	"	"	"		-3.09	- .16	108.1	102.5
183	D-64	5503	"	1530	"	"	"	"	"	"		-4.17	- .25	81.8	75.0
184	D-68	272719	"	1612	"	"	8	"	"	55°F	3°03'	- .28 -1.10	+ .13 + .11	86.9	8[illegible].0
185	D-70	56507	"	1628	"	"	"	"	"	"		-2.42	- .06	97.9	93.0
186	D-73	90912	"	1643	"	"	"	"	"	"	3°11'	-6.11 -3.70	- .51 - .18	86.0	81.0
187	D-74	50858	"	1648	"	"	"	"	"	54°F		-2.34	+ .13	127.0	122.0

TABLE II
RHEIN MAIN LANDINGS
(LIGHT WT. COND.)

NUMBER	CLOCK NO.	SERIAL NO. OF AIRPLANE	DATE OF LANDING	TIME OF LANDING	RUNWAY HEADING	WIND DIRECTION	WIND VELOCITY (MPH)	VISIBILITY (MILES)	CEILING (FT)	TEMPERATURE (°F)	ANGLE OF ROLL AT CONTACT	VERTICAL SINKING SPEED AT CONTACT (FT/SEC)	VERTICAL ACCELERATION AT CONTACT (g's)	FORWARD GROUNDSPEED AT CONTACT (MPH)	TRUE AIR SPEED AT CONTACT (MPH)
1	AA-1	272616	31 Mar. 49	1028	249°35'	210°	2	1 3/4	UNL	56°F		-2.10	+.02	91.9	91.9
2	AA-4	56507	"	1040	"	"	"	"	"	"	3°3'	-4.50 -3.50	-.17 +.11	100.0	100.0
3	AA-5	56540	"	1044	"	115°	6	2	"	58°F	3°57'	-3.28 + .93	-.06 +.27	97.0	93.5
4	AA-6	49130	"	1056	"	"	"	"	"	"		-2.81	-.19	86.7	83.1
5	AA-8	5551	"	1108	"	"	"	"	"	"		-5.26	-.27	108.0	104.5
6	AA-10	272444	"	1116	'	"	7	2½	"	61°F		-3.66	-.15	91.1	87.7
7	AA-13	5626	"	1127	"	"	"	"	"	"		-5.08	-.30	90.9	87.2
8	AA-15	272658	"	1137	"	"	"	"	"	"		-3.04	-.01	90.6	87.0
9	AA-16	56543	"	1149	"	"	5	2 3/4	"	63°F		-2.45	+.01	94.6	91.0
10	AA-20	272708	"	1159	"	"	"	"	"	"		-1.73	-.05	94.9	91.1
11	AA-21	50866	"	1203	"	"	"	"	"	"		-3.12	-.08	101.8	98.0
12	AA-23	5504	"	1226	"	-	Calm	3	"	64°F		-1.53	.00	91.5	91.5
13	AA-24	50852	"	1230	"	-	"	"	"	"		-2.51	+.07	99.8	99.8
14	AA-28	5488	"	1253	"	-	"	"	"	"		-3.29	-.18	82.6	82.6
15	AA-30	272575	"	1306	"	-	"	"	"	"		-2.90	-.08	90.4	90.4
16	AA-31	272652	"	1315	"	-	"	"	"	65°F		-4.01	-.12	94.1	94.1
17	AA-32	56544	"	1316	"	-	"	"	"	"		-4.16	-.17	91.9	91.9
18	AA-34	317199	"	1327	"	-	"	"	"	"		---	---	87.6	87.6
19	AA-36	5842	"	1332	"	-	"	"	"	"		-3.11	-.12	97.5	97.5
20	AA-37	5544	"	1339	"	-	"	"	"	66°F		-3.24	-.19	89.1	89.1
21	AA-38	5564	"	1352	"	-	"	"	"	"		-0.71	+.06	85.2	85.2
22	AA-40	272459	"	1410	"	-	"	"	"	"	3°05'	+0.14 -1.26	+.01 +.14	87.1	90.5
23	AA-41	272562	"	1414	"	270°	4	5	"	68°F		-2.08	-.01	101.5	105.0
24	AA-42	272566	"	1423	"	"	"	"	"	"		-3.59	-.33	97.3	101.0
25	AA-43	5498	31 Mar. 49	1428	249°35'	270°	4	5	UNL	68°F		-4.40	-.07	95.7	99.0
26	AA-45	317219	"	1435	"	"	"	"	"	"		-3.71	-.18	88.0	91.2
27	AA-51	5583	"	1514	"	360°	5	7	"	71°F		-2.12	-.07	105.8	105.2
28	AA-52	272505	"	1518	"	"	"	"	"	"		-3.07	-.13	81.5	80.0
29	AA-54	49119	"	1525	"	"	"	"	"	"		-2.18	-.14	84.3	83.0
30	AA-55	5602	"	1528	"	"	"	"	"	"		-3.48	-.35	95.9	94.5
31	AA-56	56540	"	1530	"	"	"	"	"	"		-2.54	-.07	95.7	94.0
32	AA-58	272719	"	1538	"	"	"	"	"	"		-2.00	+.11	99.7	98.1
33	AA-59	49130	"	1539	"	"	"	"	"	"		-4.16	-.27	93.9	93.0
34	AA-61	90921	"	1545	"	310°	4	7	"	73°F		-1.03	+.07	85.3	87.0
35	AA-63	272579	"	1556	"	"	"	"	"	"		-3.62	-.03	83.6	85.4
36	AA-67	5491	"	1621	"	-	Calm	"	"	"		-1.86	+.04	92.3	92.3
37	AA-68	272658	"	1625	"	-	Calm	"	"	"		-2.39	-.07	94.4	94.4
38	AA-71	56543	"	1635	"	-	"	"	"	"		-3.59	-.15	95.7	95.7
39	AA-77	272569	1 Apr. 49	0950	"	45°	4	2½	"	53°F		-4.62	-.10	79.2	75.5
40	AA-83	5587	"	1009	"	"	"	"	"	"		-2.22	.00	91.2	88.0
41	AA-84	5491	"	1012	"	0°	"	"	"	54°F		-3.50	-.13	96.2	95.2
42	AA-88	317245	"	1034	"	"	"	"	"	"		-3.02	-.02	83.0	82.3
43	AA-89	317199	"	1038	"	"	"	"	"	"		-1.62	+.12	92.4	91.4
44	AA-92	56522	"	1044	"	45°	"	"	"	55°F		-1.70	+.19	99.3	96.0
45	AA-94	49032	"	1054	"	"	"	"	"	"		-5.44	-.33	90.7	87.0
46	AA-95	50858	"	1057	"	"	"	"	"	"		-4.89	-.20	93.6	90.0
47	AA-96	56541	"	1102	"	"	"	"	"	"		-1.77	.00	91.1	87.5
48	AA-98	5515	"	1108	249°35'	45°	4	2½	"	"		-2.52	-.05	84.9	81.0
49	BB-1	272608	1 Apr. 49	1122	249°35'	45°	4	2½	UNL	56°F		-2.76	+ .01	92.3	89.1
50	BB-5	317233	"	1145	"	0°	3	3	"	58°F		-5.28	-.35	91.9	91.7
51	BB-6	272465	"	1150	"	"	"	"	"	"		-2.35	-.05	90.4	90.3
52	BB-7	87757	"	1157	"	"	"	"	"	"		-2.51	-.01	83.0	82.5
53	BB-9	49119	"	1215	"	225°	5	4	"	60°F		-1.77	+ .10	97.9	102.4
54	BB-10	272524	"	1218	"	"	"	"	"	"		-2.62	+.07	78.6	82.9
55	BB-13	50855	"	1243	"	-	Calm	"	"	63°F		-2.76	-.11	88.3	88.3

TABLE II (Cont.)
RHEIN MAIN LANDINGS
(LIGHT WT. COND.)

NUMBER	CLOCK NO.	SERIAL NO. OF AIRPLANE	DATE OF LANDING	TIME OF LANDING	RUNWAY HEADING	WIND DIRECTION	WIND VELOCITY (MPH)	VISIBILITY (MILES)	CEILING (FT)	TEMPERATURE (°F)	ANGLE OF ROLL AT CONTACT	VERTICAL SINKING SPEED AT CONTACT (FT/SEC)	VERTICAL ACCELERATION AT CONTACT (g's)	FORWARD GROUNDSPEED AT CONTACT (MPH)	TRUE AIR SPEED AT CONTACT (MPH)
56	BB-17	5500	"	1317	"	-	"	"	"	65°F		-4.04	-.09	92.2	92.2
57	BB-20	272603	"	1345	"	-	"	"	*45	"		-2.62	-.19	82.8	82.8
58	BB-21	90393	"	1350	"	-	"	"	"	"		-1.65	-.07	91.0	91.0
59	BB-22	50866	"	1359	"	-	"	"	"	"		-4.77	-.04	102.1	102.1
60	BB-23	50859	"	1408	"	-	"	"	"	"		-5.31	-.24	91.9	91.9
61	BB-24	56528	"	1416	"	0°	4	"	40	66°F		-2.73	+.02	87.3	86.3
62	BB-26	49048	"	1425	"	"	"	"	"	"		-2.83	-.03	100.0	99.8
63	BB-30	50854	"	1444	"	160°	"	5	"	67°F		-0.75	+.24	82.0	81.9
64	BB-35	5548	"	1523	"	90°	"	6	"	68°F		-4.76	-.35	91.4	87.5
65	BB-36	50852	"	1530	"	"	"	"	"	"		-2.42	+.03	90.1	86.0
66	BB-37	5510	"	1539	"	"	"	"	"	"		-1.52	00	93.2	89.1
67	BB-38	5582	"	1543	"	-	Calm	"	"	67°F	2°31'	-5.05 -4.19	00 +.04	97.9	97.9
68	BB-42	5583	"	1557	"	-	"	"	"	"		-5.00	-.35	91.8	91.8
69	BB-46	50858	"	1621	"	-	"	"	"	"		-3.37	-.02	92.3	92.3
70	BB-48	5486	2 Apr. 49	0943	"	-	"	"	UNL	56°F	3°36'	-2.56	+.04	123.5	123.5
71	BB-49	272667	"	0948	"	-	"	"	"	"		-3.92	-.15	102.2	102.2
72	BB-51	272603	"	0954	"	-	Calm	"	"	"		-5.57	-.36	97.9	97.9
73	BB-58	272465	2 Apr. 49	1021	249°35'	300°	4	6	UNL	59°F		-2.65	-.12	85.2	89.0
74	BB-61	272652	"	1034	"	"	"	"	"	"		-2.24	+.03	111.2	114.5
75	BB-63	5544	"	1040	"	"	"	"	"	"		-3.13	-.17	101.1	103.5
76	BB-65	50855	"	1054	"	160°	3	"	"	60°F		-2.88	-.17	98.2	98.2
77	BB-66	317219	"	1058	"	"	"	"	"	"		-3.12	-.21	90.7	90.7
78	BB-67	5500	"	1130	"	-	Calm	"	"	61°F		-2.96	-.02	99.8	99.8
79	BB-68	50868	"	1133	69° 35'	-	"	"	"	"		-2.78	+.01	74.9	74.9
80	BB-69	49032	"	1139	"	-	"	"	"	"		-3.39	+.03	95.8	95.8
81	BB-70	5488	"	1146	"	180°	5	10	"	64°F		-1.24	+.03	102.8	101.6
82	BB-72	56505	"	1158	"	"	"	"	"	"		-6.43	-.28	80.8	79.0
83	BB-73	317221	"	1203	"	"	"	"	"	"	3°29'	-2.10 -2.02	+.19 +.12	83.6	81.2
84	BB-74	50854	"	1212	"	200°	4	"	"	66°F		-4.34	-.09	84.9	82.5
85	BB-79	317245	"	1240	"	"	"	"	"	"		-3.22	.00	91.4	89.2
86	BB-85	317233	"	1312	"	"	10	"	"	67°F		-2.03	+.09	83.8	77.5
87	BB-87	272615	"	1318	"	"	"	"	"	"		-4.14	-.14	82.3	76.0
88	BB-91	272440	"	1357	"	140°	3	"	"	68°F		-2.18	+.04	88.9	89.8

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TABLE III

SAMPLE CALCULATION

TED NO. NAM STATISTICAL SURVEY OF AIRPLANE LANDINGS DURING SERVICE OPERATIONS

DATE LANDING NUMBER A-87 TYPE LANDING

NUMBER	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪	⑫
	T SECONDS	h_p INCHES	h_s INCHES	x_3 INCHES	w_1 INCHES	$\frac{1}{w_1}$	$\frac{x_3}{w_1}$	$\frac{h_{av}}{w_1}$	K_v	$\frac{h_{av}}{w_1} \times K_v$	K_a	$\frac{h_{av}}{w_1} \times K_a$
		(Height Left Wheel)	(Height Right Wheel)			$\frac{1}{⑤}$	④ x ⑥	$\frac{②+③}{2}$ x ⑥		⑧ x ⑨		⑧ x ⑪
			TOUCH	DOWN								
0	55.928											
1	55.966	+.03	(+.035) +.04		1.99	.5025		+.0176	+13.52	+.2380	+12.29	+.2163
2	56.004	+.03	(+.03) +.03	2.29	2.00	.5000	1.1450	+.0150	+4.46	+.0669	+5.59	+.0838
3	56.042	+.03	(+.03) +.03		2.01	.4975		+.0149	-2.61	-.0389	+.22	+.0033
4	56.079	+.03	(+.03) +.03	2.32	2.02	.4950	1.1484	+.0148	-7.70	-.1140	-3.80	-.0562
5	56.118	+.03	(+.03) +.03		2.03	.4926		+.0148	-10.82	-.1601	-6.48	-.0959
6	56.156	+.02	(+.02) +.02	2.34	2.04	.4902	1.1471	+.0098	-11.96	-.1172	-7.82	-.0766
7	56.194	+.02	(+.02) +.02		2.05	.4878		+.0098	-11.12	-.1090	-7.82	-.0766
8	56.233	+.02	(+.02) +.02	2.36	2.06	.4854	1.1455	+.0097	-8.30	-.0805	-6.48	-.0629
9	56.271	+.01	(+.015) +.02		2.07	.4831		+.0072	-3.51	-.0253	-3.80	-.0274
10	56.309	+.01	(+.015) +.02	2.38	2.08	.4808	1.1443	+.0072	+3.27	+.0235	+.22	+.0016
11	56.347	+.01	(+.01) +.01		2.10	.4762		+.0048	+12.02	+.0577	+5.59	+.0268
T.D. 12	56.385	+.01	(+.01) +.01	2.41	2.12	.4717	1.1368	+.0047	+22.75	+.1069	+12.29	+.0578

(17)		-.1520	(20)		-.0060
(18)	$(①_{12} - ①_0) \times 10$	4.57	(21)	(19) / (18)	3.21
(19)	(8) / (18)	14.675	A_v	(20) x (21)	-.02
V_v	(17) x (19)	-2.23			

(1) = Σ① 8,10,12 - Σ① 2,4,6 +.688

(2) = Σ⑥ 2,4,6 - Σ⑥ 8,10,12 +.0473

(3) = Σ⑦ 2,4,6 - Σ⑦ 8,10,12 +.0139

NOTE: $\Sigma ①_{i,j,k} = \Sigma ①_i + \Sigma ①_j + \Sigma ①_k$

W	14.16	MODEL	C-54
2W	28.32	TYPE OPER.	BERLIN AIRLIFT
M = W / .95	14.9053	ON BOARD	TEMPELHOF
θ	13	BU. NO.	
S/2	33.25	PILOT	
F	1.9685	WIND VEL.	
F' = F x M	29.3411	AIRPLANE GROSS WT.	
2F'	58.6822		

CALC. OF V_H AT TOUCH-DOWN

(4)	x_1	1.53
(5)	x_2	3.64
(6)	[(4) + (5)] / 2W	.1826
(7)	cos. function	2.017
(8)	S' = S/2 x (7)	67.065
(9)	(8) / (1)	97.4782
(10)	F' x (2)	1.3878
(11)	V_y = (10) x (9)	135.2802
(12)	(3) / (10)	.0100
(13)	W / 2F'	.2413
(14)	tan∝ (12) - (13)	-.2313
(15)	cos∝	.9743
V_H	[(11) / (15)] x .5921	82.21
	AIR SPEED	

*Film Width .95

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